US Army Corps
of Engineers®
Northwestern Division

PACIFIC LAMPREY PASSAGE IMPROVEMENTS IMPLEMENTATION PLAN: 2008 – 2018

2014 REVISION

December 2014 Final Report

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

AL	adult lamprey
AWS	auxiliary water supply
BON	Bonneville Dam
CI	Cascades Island Fish Ladder
Corps	U.S. Army Corps of Engineers
CRBLTWG	Columbia River Basin Lamprey Technical Work Group
CRFM	Columbia River Fish Mitigation
CRITFC	Columbia River Inter-Tribal Fish Commission
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
FPC	Fish Passage Center
JBS	Juvenile Bypass Systems
JDA	John Day Dam
JDAN	John Day North Fish Ladder
JFF	Juvenile Fish Facility
LFS	Bonneville Washington Shore Ladder - Lamprey Flume System
LGS	Little Goose Dam
JL	juvenile lamprey
LMN	Lower Monumental Dam
LPS	Lamprey Passage Structure (or System)
LWG	Lower Granite Dam
MCN	McNary Dam
MOA	Memorandum of Agreement
O&M	Operations and Maintenance
OP	overall program
PNNL	Pacific Northwest National Laboratory
PRD	Priest Rapids Dam
SMP	Smolt Monitoring Program
TDA	The Dalles Dam
USACE	United States Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service

INTRODUCTION

In May 2008, a Memorandum of Agreement (MOA) between the Action Agencies, the Accord Treaty Tribes (consisting of the Umatilla, Warm Springs, and Yakama Tribes) and the Columbia River Inter-Tribal Fish Commission addressed actions to protect Pacific lamprey (see the following website for the document: http://www.critfc.org/fish-and-watersheds/fish-and-habitat-restoration/columbia-basin-fish-accords/. Specific to the U.S Army Corps of Engineers (USACE), the MOA required collaboration with the tribes and the U.S. Fish and Wildlife Service (USFWS) to develop and implement a 10-year lamprey passage improvement plan. The goal of this plan is to identify specific actions that can be taken to improve lamprey passage at USACE dams along the lower Columbia and Snake rivers. The following is a summary of USACE commitments to improve Pacific lamprey passage as a part of the 10-year Plan and includes Action Agency commitments for past, present and future actions to benefit lamprey affected by the Federal Columbia River Power System (FCRPS). The U.S. Army Corps of Engineers will:

<u>Overall Program (OP)</u>

1) Employ an adaptive management approach.
2) Work with the tribes and the USFWS towards developing its existing 5-year lamprey plan into a 10-year plan, covering both adult and juvenile passage issues.
3) Program $1.8 million in 2008 with funding ramping up to $2-$5 million per year for 10 years.

<u>MOA Adult Lamprey</u>

1) Address adult lamprey (AL) passage in the main stem hydropower projects using PIT/radio-telemetry to determine overall effectiveness.
2) Develop numerical passage metrics through the Lamprey Technical Workgroup.
3) Conduct site inspections of each dewatered fish ladder.
4) Evaluate, fully develop and implement as warranted Lamprey Auxiliary Passage Systems (LPS).
5) Evaluate reducing entrance flows at night to assist lamprey entrance passage; and as warranted, expand through FCRPS main stem dams.
6) Complete keyhole entrances Cascade Island 2009 and John Day North 2010/2011 then implement as warranted through FCRPS main stem dams.
7) Inventory all picketed leads, fish way cracks, blind openings and ladder exits. Begin replacing existing grating with new 3/4” grating in most identified problem areas.
8) Round sharp corners as warranted.
9) Develop feasibility, techniques and protocols for counting.

MOA Juvenile Lamprey

1) Continue to monitor the passage timing, number, and mortalities of juvenile lamprey (JL) collected at projects with juvenile fish bypass facilities.
2) Replace with smaller gap screens as warranted when turbine intake bar screens are in need of replacement.
3) Consider lifting extended length screens (primarily at McNary but also at Columbia and Snake River dams) in consultation with the NOAA and the Tribes.
4) Develop prototype Lamprey separators.
5) Work actively with industry to further miniaturize active tags then determine passage routes, out migrant timing and survival of lamprey through FCRPS main stem dams.

The first iteration of the 10-year plan *Pacific Lamprey Passage Improvements Implementation Plan: 2008-2018* was completed in July 2009. This plan built on research, monitoring, and passage modifications completed prior to 2008 and outlined a preliminary plan for addressing the Memorandum of Agreement actions summarized above. Per MOA OP1 above, USACE agreed to pursue an adaptive management approach in executing this preliminary plan. While progress has been documented in annual progress reports, USACE and our partnering Tribes agreed in 2013 that it would be useful to draft this revised implementation plan based on actions completed and lessons learned from 2008-2013.

As was the case with the first version of the 10-year plan, commitments are abbreviated for ease of reference. For example, "MOA AL 1" is the abbreviation for MOA AL – 1: "Address adult lamprey conditions in the main stem hydropower projects using PIT/radio-telemetry to determine overall effectiveness". Included is a summary of past research and implementation actions that have led us to the strategy employed in the implementation plan, though readers are encouraged to seek complete study reports for further details. Appendices included in the first version of the 10-year plan were not included in this revised version to avoid redundancy and confusion.

This is a living document and this program's overall strategy is aggressive and innovative. It will take all Parties working together in a cooperative and adaptive management mode to succeed at making meaningful and long-lasting improvements to Pacific lamprey passage. In 2008, USACE began meeting regularly with MOA Treaty Tribes and Columbia River Inter-Tribal Fish Commission (CRITFC) to discuss lamprey passage implementation and funding issues, including priorities and impediments.

BACKGROUND

Pacific lamprey (*Entosphenus tridentatus*) is the largest native lamprey species found in the Columbia Basin. They generally migrate upriver during March to October in the year prior to spawning, overwinter in deep pools, and spawn in the spring (April to July) when water temperatures reach 50° to 59°F in areas of fine gravel and silt by excavating shallow depressions. One female lamprey may deposit from 40,000 to 238,000 eggs depending upon their body size. The eggs generally hatch into larvae after 2 to 3 weeks, residing for 4 to 7 years in low velocity areas within silt/mud substrates. They feed by filtering the passing water for microscopic plants and animals. These larvae develop no eyes or teeth until the time they are physiologically transforming to leave freshwater for seawater. At this stage, they develop a sucker-like mouth and become parasitic, attaching to other host fish and feeding on body fluids.

Juvenile and adult lampreys become more active during the hours of darkness and spend much of the daylight hours attached to substrate. Because lampreys lack swim bladders, they are typically found low in the water column. Downstream migration is usually associated with turbid, higher spring runoff, the combination of which serves to reduce the potential for predation during migration.

When returning to fresh water after 2 to 3 years, adult Pacific lamprey must use the same fishways as adult salmonids to migrate upstream past the FCRPS dams (Table 1). Because these fishways were designed and modified to maximize salmonid passage, lamprey face conditions that are not optimal and often are impediments to the way they swim and move upstream. For example, during shad passage season, head over weir criteria is increased by 0.3 ft to ensure efficient movement of the large numbers of migrating shad up the ladders and prevent blockages which in turn can delay salmon passage. This action, which coincides with adult lamprey passage season, increases fishway entrance velocities, which already present a major challenge to Pacific lamprey.

Pacific lamprey have declined in numbers in the Columbia Basin since the 1960s. Scientists have attributed the decline to several causes including pollution, habitat loss, irrigation, intentional removal, ocean conditions, and dam passage. This decline has lead to significant regional concern regarding lamprey populations in the Columbia Basin. In 1993, the Oregon Department of Fish and Wildlife designated Pacific lamprey at risk of being listed as threatened or endangered. The tribes have repeatedly voiced concern about the decline of Pacific lamprey, a culturally important species. On January 28, 2003, the Pacific lamprey was petitioned for listing under the ESA. However, no funds were committed in 2003 or 2004 to make a determination. As a result, "intent to sue" was filed in March 2004 for failing to act on the petition, and in June the suit was filed. In January 2005, a "finding of insufficient information to evaluate status" was determined by the USFWS. It is possible that Pacific lamprey will again be petitioned for ESA listing, especially if their numbers continue to decline.

Table 1. Annual adult Pacific lamprey daytime window counts at Bonneville (BON), The Dalles (TDA), John Day (JDA), McNary (MCN), Priest Rapids (PRD), Ice Harbor (ICH), and Lower Granite (LGR) Dams: 2000 – 2013 (* counts through 3 October 2013). No corrections for night video, LPS, or count station picket lead counts are included, so this table should be used only as a long-term index. For example, according to USACE records (day and night counts, LPS count estimates, and collected lamprey released above the dams) the total estimated number of adult lamprey passing Bonneville Dam in 2012 was 93,456 (320% of the day count index).

ADULT PACIFIC LAMPREY PASSAGE INDEX (DAYTIME WINDOW COUNTS)							
YEAR	BON	TDA	JDA	MCN	PRD	ICH	LGR
2000	19,002	8,050	5,844	1,281	1,468	315	28
2001	27,947	9,061	4,005	2,539	1,624	203	27
2002	100,476	23,417	26,821	11,282	4,007	1,127	128
2003	117,029	28,995	20,922	13,325	4,339	1,702	282
2004	61,780	14,873	11,668	5,888	2,647	805	117
2005	26,664	8,361	8,312	4,158	2,598	461	40
2006	38,938	6,894	9,600	2,456	4,381	277	35
2007	19,313	6,085	5,731	3,454	6,593	290	34
2008	14,562	4,599	6,625	1,530	5,083	264	61
2009	8,622	2,318	2,044	676	2,714	57	12
2010	6,234	1,726	1,662	825	1,114	114	15
2011	18,315	5,003	3,566	868	3,868	269	48
2012	29,224	6,241	4,587	970	4,025	484	48
2013*	23,864	8,717	6,614	1,565	5,756	321	19

GOAL

The goal of the Pacific lamprey passage program within the Northwestern Division of USACE is to improve lamprey passage at USACE dams along the lower Columbia and Snake rivers.

FUNDING

Columbia River Fish Mitigation (CRFM) is the primary USACE program that provides funding for protecting, mitigating, and enhancing anadromous fish such as salmon and steelhead at USACE dams. Through CRFM, USACE is funding lamprey research, monitoring and evaluations. Operation and

Maintenance (O&M) funds have also been used to aid lamprey passage efforts at Columbia and Snake River dams.

USACE TEAM DISCIPLINES

The USACE team disciplines anticipated for this ongoing effort include fishery biology, environmental resources, hydraulic engineering, structural engineering, mechanical engineering, electrical engineering, civil engineering, cost estimating, construction, and specific Project personnel including dam operators and rigging and maintenance crews; considerations will need to be assessed dam by dam and project by project. Concurrently, system-wide programmatic environmental ESA compliance discussions are underway with salmon managers about implementation of the lamprey plan and how the plan and actions described within the plan may influence salmon recovery efforts. Since ladder modifications would occur within existing concrete dam structures, real estate issues are not anticipated. The short in-water-work periods at the ladders present challenges that will need to be addressed and may be mitigated through prefabrication of key components. All information provided below is subject to refinement with on-going research, team project development, and monitoring and is provided for internal agency use, dialogue, and deliberation.

ANNUAL REPORTING

An annual report summarizing the progress to date will be provided early in each calendar year, which will include Research, Implementation, all adaptive management decisions and Fiscal Year expended costs. BPA and the Bureau of Reclamation will be encouraged to provide concurrent summaries which will be incorporated into one summary.

IMPLEMENTATION CONTEXT AND STRATEGY

Implementation of effective passage improvements for adult and juvenile Pacific lamprey is contingent on several factors, including:

1. Understanding of lamprey passage behavior;
2. Identification of key passage bottlenecks and relative impacts on passage;
3. Compatibility of passage modifications with ESA-listed salmon passage, and;
4. Availability of resources commensurate with the technical challenges of modifying passage facilities.

There is an urgent need to address passage as part of a regional effort to restore Pacific lamprey to the interior Columbia River Basin. While pre-2009 field and lab studies provided some good baseline information for understanding and addressing mechanisms of lamprey passage failure at dams, there are gaps in knowledge concerning Pacific lamprey behavior, passage, and life cycle. An adaptive management approach will be continued to ensure effective and timely modifications at USACE dams along the lower Columbia and Snake rivers and to optimize the use of limited available resources.

From 2009 through 2012, the primary focus of USACE lamprey passage efforts was on design, construction, and initial evaluations of relatively large-scale adult fishway entrance modifications. This was based on historic telemetry data that suggested that fishway entrances were problematic and a prioritization strategy to prioritize efforts where: (1) passage effectiveness is poorest, and (2) where the potential for adverse effects on lamprey are the highest. Since dam fishway entrances are the first and seemingly largest passage barrier encountered by most adult Pacific lamprey, USACE and our partners reasoned that improving entrances for adult lamprey passage – concerning at least one major entrance modification per project at most USACE dams along the lower Columbia and Snake rivers– should be an initial focus of the program. To address other problematic adult and juvenile fishway features, USACE also made smaller-scale improvements, as limited resources allowed, to fish ladders and bypass facilities. Concurrently, USACE-funded researchers continue to develop handling and tagging protocols for future acoustic telemetry-based juvenile lamprey passage evaluations.

Based on lessons learned and progress made since 2009, USACE proposes to continue this strategy, with a few notable diversions that can be summarized as follows:

1. Increased focus on addressing adult lamprey passage bottlenecks in fishway sections that are upstream of entrances (i.e. transition pools, serpentine weirs). Post-hoc evaluation of historic telemetry data suggests this will enhance likelihood of improving overall dam passage efficiency and conversion to upriver dams (Keefer et al. 2013).
2. Based on success of BON Cascades Island Ladder entrance LPS and preliminary success at JDA North Ladder, and apparent benign effects on salmonids, install similar systems elsewhere at ladder bottlenecks (Corbett et al. 2013).
3. Accelerate implementation of small-scale modifications at Lower Columbia dams (BON, TDA, and JDA).
4. Consider alternative approaches to inform management decisions regarding juvenile lamprey passage improvements, other than the current strategy of developing juvenile lamprey acoustic transmitter. Managers should consider technological feasibility, schedule, cost, and ESA obligations.

PRIORITIZATION

It is critical to determine and agree on prioritization of problem areas, research and monitoring needs, and implementation of improvements to ensure the most efficient use of time and money toward improving Pacific lamprey passage. The Columbia River Basin Lamprey Technical Workgroup (CRBLTWG) has identified the need to improve adult lamprey passage at Columbia River hydropower dams as one of the highest priorities for Pacific lamprey recovery.

Efforts to improve lamprey passage should be prioritized where:

1. Where passage effectiveness is the poorest, and
2. Where the potential for adverse passage effects on Pacific lamprey are the highest.

This approach will maximize the improvements for both upper and lower Columbia Basin Pacific lamprey and is particularly important when investing in larger-scale modifications or studies. Other factors, such as fish ladder availability during particular maintenance periods and availability of cost-effective measures to modify known problems, also influence implementation decisions. In practice, this has resulted in an initial focus on improving adult lamprey passage at Bonneville Dam, since this is the lowest passage barrier encountered and has consistently demonstrated poor dam passage efficiency (number of successful passage attempts as a proportion of lamprey that approach the dam).

Given the ongoing need to improve adult Pacific lamprey passage, USACE will continue to generally prioritize adult lamprey passage efforts over juvenile lamprey efforts until such time appropriate tools are developed for evaluating juvenile lamprey passage. In doing this, we assume that restoring migration corridors for adult lamprey is the critical first step –as was the case with salmon restoration efforts in the basin – in restoring Pacific lamprey in the Columbia River Basin. Furthermore, we have a much better understanding of adult lamprey passage behavior and success and thus are better prepared at this time to address adult lamprey passage problems. While some progress has been made in studying and addressing known juvenile lamprey passage problems since 2008, it is important to note that there is a poor understanding of juvenile Pacific lamprey passage and survival at dams. USACE currently expects that future acoustic-telemetry studies, should they be prioritized, would inform how operations and configurations of dams may be modified to improve juvenile lamprey passage success.

With respect to research, monitoring and evaluations (RM&E), USACE will continue to prioritize studies that will directly inform design and evaluation of passage improvements for lamprey. While USACE continues to support pursuit of broader life-history and population-level research questions, this program must, by necessity, keep limited resources focused on studies with direct management implications for how USACE operates and configures FCRPS dams.

ADULT LAMPREY PASSAGE

INITIAL ADULT LAMPREY PASSAGE STUDIES: 1997-2002

Radio-telemetry work in 1997 to 2002 indicated that adult Pacific lamprey passage efficiency at Bonneville Dam (the percentage of lamprey that successfully passed over the dam of those that approached the dam base) was less than 50% in all years (Moser et al. 2002b; Moser et al. 2005b; Figure 1). This occurred despite approximately 90% of the lamprey tagged in all years of study returning to the base of the dam after release downstream, which indicates migrational motivation and low tagging or tailrace predation effects (Moser et al. 2002a). Passage efficiency for lamprey that approached The Dalles Dam was consistently higher than at Bonneville Dam, while passage efficiency at John Day Dam was similar to that at Bonneville Dam. Passage efficiency at The Dalles North Ladder (> 80%) was higher than passage efficiency through any other entrance evaluated. This may relate to the natural rock structure inside much of the north ladder and that there is no serpentine weir section in the exit area. Based on 2000-2002 radio-telemetry research, passage efficiencies at Bonneville, The Dalles, and John Day averaged 47%, 74%, and 53%, respectively.

Of particular concern is poor performance of lamprey at fishway entrances, through collection channels, transition pools, junction pools, and past serpentine weir sections at the top of the fishways at Bonneville Dam (Moser et al. 2002b). Tracking results indicated that lamprey pass the count window, but are obstructed in the section of the fishway ladder containing the vertical-slot weirs upstream from the count stations (Moser et al. 2003). Previous years of radio-telemetry indicated that providing lamprey with an alternative route of passage through this area (Figure 2) could increase overall lamprey passage efficiency by approximately 33%.

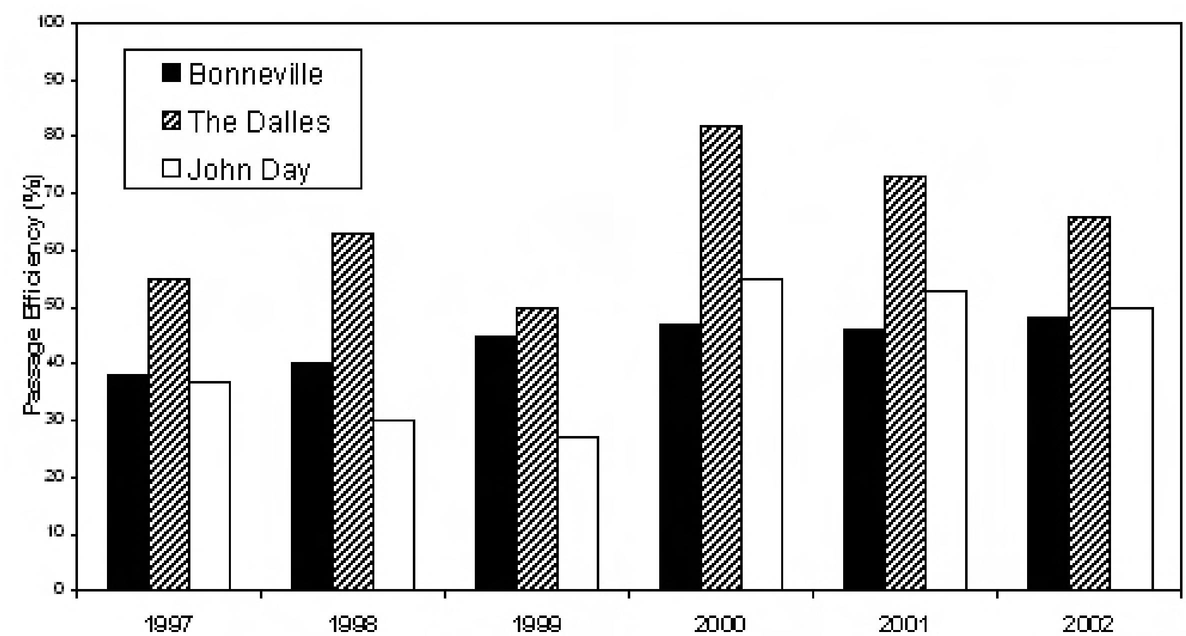

Figure 1. Overall passage efficiency (percent of lamprey that passed over each dam of those that approached each dam) for Bonneville, The Dalles, and John Day dams in 1997-2002.

Radio-telemetry studies and fishway experiments demonstrated that lamprey have difficulty entering fishways. Telemetry studies at Bonneville Dam in 1998 through 2002 indicated that lamprey entrance efficiency was particularly low at the north downstream entrance to the Washington-shore fishway (Moser et al. 2005b). During this period, less than 40% of the lampreys that approached this entrance successfully entered the fishway (Moser et al. 2005b). High flow velocities (usually 8 ft/sec or higher) may be the primary constraint for lamprey at fishway entrances.

Ladder entrance efficiency is a major passage problem at most of the USACE dams along the lower Columbia and Snake rivers (Moser et al. 2005b). At the North Downstream Entrance of Bonneville Dam's Washington Shore Ladder, where large numbers of adult Pacific lamprey first approach the dam, entrance efficiency was only around 40% from 1990-2002. In 2003, a test LPS was placed just downstream of this entrance to see if it could attract and collect many of the lamprey that were not entering the fishway. Annually, only 5% or less of the lamprey approaching this entrance have used this LPS. The lack of success is likely related to the limited attraction flow and small size of the LPS, as well as the large numbers of alternative flows and routes to explore in the area immediate downstream of the entrance.

LAMPREY PASSAGE STRUCTURES DEVELOPMENT: 2002 - 2008

Radio-telemetry results and visual observations indicated that lamprey obstructed in the serpentine weir section at the top of the fishway can accumulate in the adjacent auxiliary water supply (AWS) channel (Figures 2 and 3). Because this area poses a significant threat to lamprey passage, two prototype bypass collectors were developed in 2002 to determine if lamprey could be collected from the AWS channel at the top of the Bradford Island fishway at Bonneville Dam (Figure 3; Moser et al. 2005b). Testing of passage alternatives for lamprey at this location was done without impacting salmon passage in the main fishway. Initial testing of the lamprey collectors showed that lamprey use them. Further design refinement and testing in 2003 resulted in collector efficiencies of up to 20% and catch rates of over 250 lamprey per night (Moser et al. 2005a).

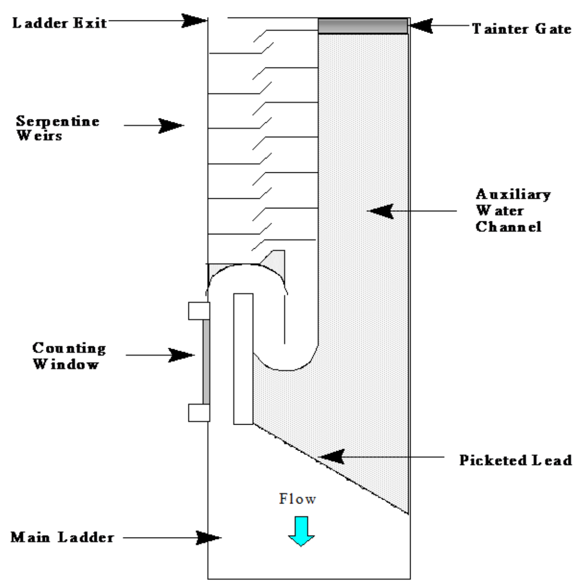

Figure 2. Overhead diagram of the top of the fishway at Bonneville Dam and the auxiliary water supply channel.

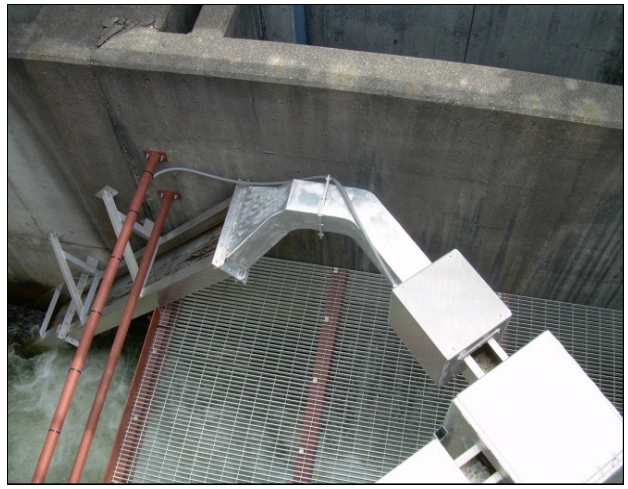

Figure 3. Bradford Island LPS ramps in the auxiliary water supply channel near the exit to the Bradford Island ladder at Bonneville Dam.

In 2004, the LPS was extended to exit directly into the Bonneville Dam forebay. With this extension, lamprey could move directly from the AWS to the forebay. This LPS was used from the day it was installed by over 8,300 lamprey in 2004 and over 9,200 lamprey in 2005. In both years, this represented a significant percentage of the total count of lamprey at the Bradford Island count station (Table 2). Consequently, a more permanent installation of the LPS with dual collection channels was installed in 2006. In 2007, monitoring lamprey use of this LPS was continued using both a lamprey-activated counter and a half-duplex PIT tag detection system (Figure 4). In 2007, a similar LPS was installed at the Washington Shore AWS and its efficacy was assessed (Figure 5).

Table 2. Pacific lamprey counts at the Bradford Island count window and through the auxiliary water supply channel.

Year	# at Count Station	Estimated Total	Bradford Island AWS	
			LPS Count	% of Estimated Total
2004	11,971	35,913	7,490	21
2005	10,257	30,771	9,242	30
2006	14,862	44,586	14,975	34
2007	6,473	19,420	7,387	38

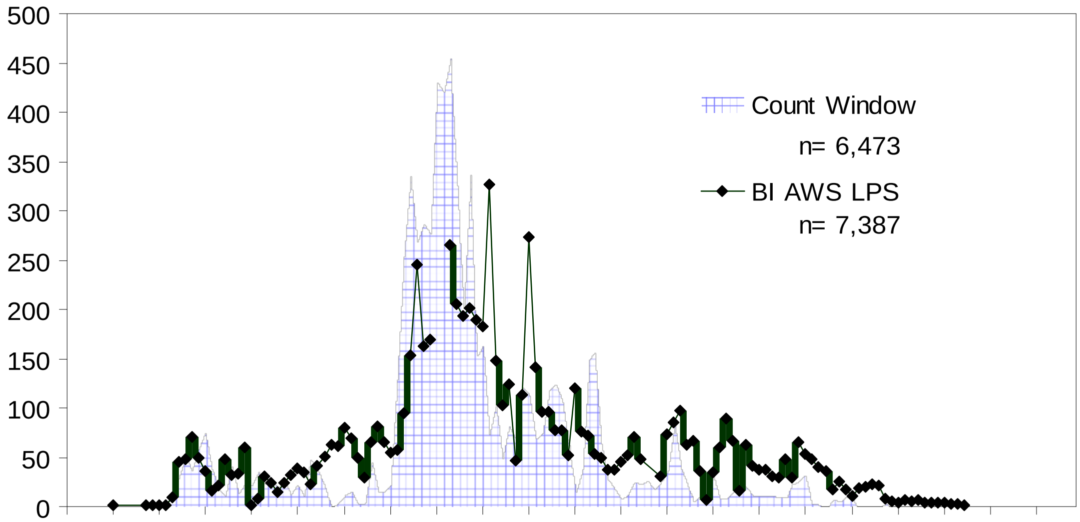

Figure 4. Pacific lamprey counts at Bradford Island count window and at the Bradford Island ladder auxiliary water channel LPS 2007.

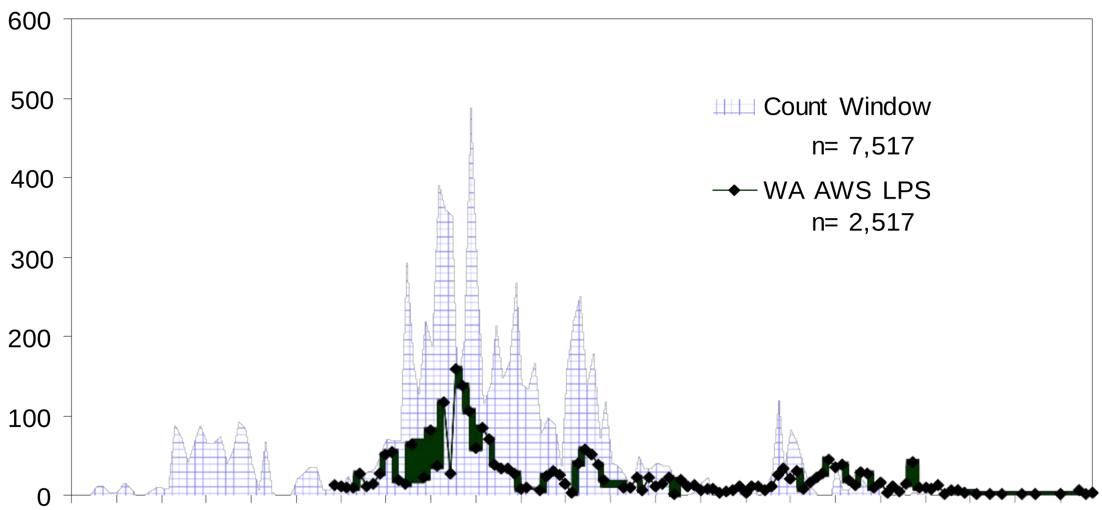

Figure 5. Pacific lamprey counts at Washington-shore count window and at the Washington-shore ladder auxiliary water channel LPS, 2007.

ADULT LAMPREY PASSAGE IMPROVEMENTS IMPLEMENTATION: 2009 - 2018

INTRODUCTION

There are two primary reasons known for adult Pacific lamprey passage challenges at USACE dams along the lower Columbia and Snake rivers. First, Pacific lamprey are less capable swimmers in high velocity flows when compared to salmon and nearly all salmon-based velocity criteria in the fish ladders may be too high for lamprey to navigate without repeatedly burst swimming, reattaching, and resting. In fishways, this behavior is observed at fishway entrances, weir orifices, count stations, and vertical slot weirs. The burst-and-attach swimming strategy requires unique fishway features, such as chamfered corners and plating over diffuser grating in high-velocity areas (Keefer et al. 2010). Given appropriate passage structure features, lamprey can perform exceptionally well; their climbing ability allows them to navigate around natural barriers such as Willamette Falls. Thus, passage designs for high-velocity problem area relatively intuitive and easy to evaluate. Examples include installation of smooth plating over diffuser grating, provision of rounded entrance weir structures, rounding of weir orifices and slots, installing lamprey specific orifices within weir walls, and development of lamprey-specific Lamprey Passage Structures (LPSs).

Second, telemetry studies suggest rejection of some lower velocity sections (1 to 4 fps) of fishways due to poorly understood hydraulic or biological cues (i.e. presence of white sturgeon). This behavior is manifested in poor passage efficiency in collection channels, transition pools, junction pools, and turning pools and accounts for much of the adult lamprey passage challenges at monitored USACE dams along the lower Columbia and Snake rivers, most notably Bonneville Dam. Because the mechanisms of passage failure in these fishway sections are poorly understood but likely complex *and* because these fishway sections are configured to ensure that passage criteria for ESA-listed salmonids is maintained, options for structural and operational fixes are limited. Currently, the strategy for addressing poor passage in these areas is to guide lamprey into alternative passage systems either outside (BON Washington Shore Lamprey Flume System) or immediately inside fishway entrances (BON Cascades Island LPS, JDA North Ladder LPS). Post-construction evaluation of the BON Cascades Island LPS suggests that this approach may be an effective means of diverting lamprey to an alternative system prior to rejection of the traditional fishway. Additionally, USACE-funded researchers have begun testing refuge structures along fishway floors to provide daytime cover (lamprey migrate more actively at night) and to potentially provide refuge from predation.

Since the early 2000s, USACE approach for addressing adult lamprey passage his largely focused on guiding lamprey out of the primary (salmon) fishways, into LPSs, and over the dam(s). Initial experimental (now fully operational) LPS installations at Bonneville Dam were located in auxiliary water supply channels near the exit (upper) sections of the Bradford Island and Washington Shore ladders. These LPSs have provided a passage route at known “dead end” areas (Corbett et al. 2013). At BON Cascades Island Ladder and at JDA North Ladder, USACE experimented with modifications to ladder entrances, adding velocity reducing structures that lead to LPS collection ramps, and the installation of LPSs that bypass passage problem areas in the ladder from the entrance area to temporary holding tanks or the forebay. The current goal is to divert as many lamprey as possible into LPSs with a preliminary target of 50%; however, USACE understands and expects that not all lamprey will be diverted.

IMPLEMENTATION CONSIDERATIONS

A key challenge to all potential Pacific lamprey designs and operations is the ability to ensure that ESA-listed salmon are not negatively affected, or that hydraulic conditions at dams set up to aid in salmonid passage are not negatively altered. Major changes to structures or operations must be reviewed through ESA consultation processes and be proven to not negatively affect salmon passage. The approach and challenge to engineering Pacific lamprey improvements is to make new designs that actually aid lamprey while either having a neutral or positive effect on salmon and steelhead passage.

Smaller scale, modification such as adding ramps, plates, or rounding at specific problem sites at USACE dams along the lower Columbia and Snake rivers will continue through 2018, depending on availability of funding. USACE maintains a list of potential modifications for each dam. Although some modifications will be directly evaluated so lessons can be applied to other projects, USACE strives to minimize post-construction monitoring for these smaller-scale, lower cost, low risk modifications. The strategy is to implement quickly based on current understanding of passage problems, with the expectation that these smaller-scale fixes will provide incremental benefits to Pacific lamprey. Many modifications were completed between 2009 and 2013, particularly at McNary and Lower Snake River dams, and in 2012, USACE Portland District created a dedicated Project Delivery Team (PDT) to accelerate minor fishway modifications at Bonneville, The Dalles, and John Day dams. Periodic site visits have included participants from tribal, state, and federal agencies and have helped shape the current list of proposed modifications.

Prioritization decisions and schedules will be determined and potentially modified over the years in consultation with Accord Treaty Tribes, CRITFC, and other regional partners, and will be dependent on the availability of funding and the success of prototype evaluations at FCRPS dams and elsewhere. In 2012, the U.S. Fish and Wildlife Service prepared the report *Systematic Fishway Survey and Evaluation for Upstream Passage of Adult Pacific Lamprey at the FCRPS Projects in the Mainstem Columbia and Snake Rivers* (Wills and Anglin 2012) which included recommendations on future actions and information needs for adult lamprey passage improvements. Many of these suggestions have been integrated (directly or indirectly) into the actions detailed below and USACE will continue to consult with USFWS on passage improvement actions for Pacific lamprey.

In order to accomplish evaluations of prototype systems and improvements, adequate numbers of test fish will need to be available for tagging. This may limit where such prototypes can be tested to areas far enough downstream and with the capability to capture and tag required sample sizes, such as at Bonneville Dam. This does not mean that installation of specific features known to benefit lamprey should not occur at upriver priority dams if there are known specific problem areas and large benefits. Adding lamprey design features to any ongoing or planned work in the fishways should also occur regardless of where they stand on the priority list.

Below, we provide an accounting of progress on each MOA item, along with proposed actions through 2018.

MOA AL 1: ADDRESS ADULT LAMPREY PASSAGE IN THE MAINSTEM HYDROPOWER PROJECTS USING PIT/RADIO-TELEMETRY TO DETERMINE OVERALL EFFECTIVENESS.

Active (radio and acoustic) and passive (PIT) telemetry tools provide USACE and our partners with passage metrics that are used to evaluate behavior and passage success within fishways, in the near-dam environment, and in reservoirs. While information gleaned from initial passage studies in 1997 – 2008 provided baseline information on passage performance, our approach since 2008 – particularly at Bonneville Dam – has been to use telemetry tools to compare passage efficiency and time at areas of interest before and after modifications. Additionally, tagged lamprey and arrays deployed for post-construction studies are used to assess long-term changes in broader passage metrics, such as dam-to-dam conversion. Study results are discussed below and in technical reports submitted to USACE and distributed to regional fish managers.

Radio-telemetry and PIT study results, along with daytime window counts, have suggested poor conversion of adult lamprey from the top of Bonneville Dam to fishway entrances at The Dalles Dam. At the request of USACE, the University of Idaho summarized study results, including past experimental flume study results, in a synthesis report intended to facilitate prioritization of future fishway modifications (Keefer et al. 2013). Efforts are currently underway to pair telemetry data and other information (photographs, hydraulics, etc) with isometric renderings and two-dimensional illustrations of fishways to help managers inform decisions on future actions and to assist in keeping track of completed modifications.

Since 2009, USACE-funded researchers from the University of Idaho have attempted, with mixed success, to use acoustic telemetry to augment our understanding of the fate of lamprey that do not convert from BON to TDA. While these studies have provided new information on lamprey migration in the area of interest, including the fate of overwintered lamprey, this study has not yet yielded results that definitively accounted for the observed conversion rates (Noyes et al. 2012). In 2014 – 2018, USACE will continue to collaborate with regional fish managers and researchers to determine the most appropriate course for addressing this important question.

In addition to telemetry studies, it should be noted that alternative tools may be used to determine effectiveness of certain passage modifications. Since 2008, USACE has increasingly relied on visual technologies, such as optical video and high-resolution SONAR to evaluate meso- and fine-scale behavior in and around fishways. For example, Johnson et al. (2013) used Dual-frequency Identification Sonar (DIDSON)* to evaluate behavior of adult lamprey in the lower ladder and entrance area at JDA North Ladder as part of a broader study of the efficacy of modifications in these areas. Similarly, conventional video was used to evaluate lamprey behavior at lamprey orifices installed in the tilting weir stem walls at MCN Oregon Shore Ladder in 2010 (Eder et al. 2011), and optical video and DIDSON have been used to monitor picket lead sections of the count stations at MCN and ICH as well as areas upstream of the counting stations to determine if alternate locations exist to capture total escapement estimates through the ladders in 2011 (Thompson et al 2012). USACE intends to continue to supplement telemetry studies with these non-invasive video tools as appropriate.

Does not constitute an endorsement of these products by the U.S. Army Corps of Engineers.

MOA AL 2: DEVELOP NUMERICAL PASSAGE METRICS THROUGH LAMPREY TECHNICAL WORKGROUP.

At present, there is no specific target or goal for performance of Pacific lamprey passage and there is great uncertainty about how to meaningfully establish such a standard. In September 2007, the CRBLTWG was tasked with trying to develop such performance standards but admits that, "In general, information is not currently adequate to develop long-term objectives for either life stage" (September 24, 2007 meeting minutes, CRBLTWG Passage Standards Subgroup).

The Passage Standards Subgroup was reconvened in 2009 and decided to use a phased approach to developing performance standards. USACE biologists participated in this effort by providing summaries of recent passage evaluations relevant to upstream passage of adult Pacific lampreys at USACE-operated dams. This information was documented in a draft report *Run Characteristics, Current Distribution, and Efforts to Improve Passage of Adult Pacific Lamprey in the Columbia River Basin, 2011* (in progress).

While recent analyses suggest correlations between adult Pacific lamprey counts at Bonneville Dam and abundance of their marine hosts (Murauskas et al. 2013), USACE recognizes that poor passage at USACE dams along the lower Columbia and Snake rivers is an important factor limiting lamprey distribution and abundance in the basin – particularly in interior basin tributaries – as evidenced by relatively poor passage efficiencies at monitored dams (Keefer et al. 2013). While it continues to be challenging to evaluate the *population*-scale benefits of dam passage improvements, USACE seeks to improve passage efficiencies at all dams by at least 10-20% through operational and structural modifications described in this document. An interim goal is to meet or exceed the total dam passage efficiency (passed dam : approached fishway) observed at The Dalles Dam, where efficiency from 1997-2010 averaged 69% (Keefer et al. 2013).

MOA AL 3: CONDUCT SITE INSPECTIONS OF EACH DEWATERED FISH LADDER.

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018
• BON Cascades Island (2010-11, 2013-14) • BON Washington Shore (2010-11, 2013-14) • TDA East and North (2010-11) • JDA South (2010-11) • JDA North (2012-13) • MCN South (2010-11, 2011-12, 2014) • MCN North (2010, 2011, 2012, 2013, 2014) • ICH North (2010, 2011, 2012, 2013) • ICH South (2010-11, 2011-12) • LMN South (2010-11, 2011-12) • LMN North (2010, 2011, 2012, 2013) • LGO Adult Ladder (2010, 2011, 2012, 2013) • LGR Adult Ladder (2010, 2011, 2012, 2014)	• BON Bradford Island (2017-18) • BON Cascades Island (2014-15, 2016-17) • BON Washington Shore (2014-15, 2016-17) • JDA North (2017-18) • MCN Oregon and Washington Shore (2015-16, 2017-18) • ICH North and South (2014-15, 2016-17) • LMN North and South (2015-16, 2017-18) • LGS Adult Ladder (2014-15, 2016-17) • LGR Adult Ladder (2015-16, 2017-18)

Fish ladder inspections are routinely used by USACE to identify maintenance needs, develop lists of potential modifications to improve passage, and to ensure quality (smooth surfaces, acceptable materials, removal of construction debris prior to operation). Project biologists and maintenance personnel routinely each dewatered fish ladders during each winter maintenance period. In part, this information was used to develop the initial list of possible lamprey passage improvements. Since 2008, USACE conducted several fishway tours with federal, state, and tribal staff. These tours were used to monitor implementation progress and to facilitate discussion of additional modifications. These fishway tours will continue through 2018, as needed.

MOA AL 4: EVALUATE, FULLY DEVELOP AND IMPLEMENT AS WARRANTED LAMPREY AUXILIARY PASSAGE STRUCTURES/SYSTEMS (LPS).

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018
• BON Cascades Island Ladder Entrance LPS (2009-10) with extension to forebay (2013) • BON Washington Shore Lamprey Flume System LPS (2012-13) • JDA North Ladder Entrance LPS (2012-13)	• Extend BON Washington Shore LFS LPS (2016-17) and JDA North LPS (2017-18) to forebay, if warranted • Additional LPS collection ramps for Cascades Island LPS and Washington Shore LFS LPS (2016-17), if warranted • New BON Bradford Island B-Branch transition pool LPS to forebay (2017-18) • Complete development of LPS counting systems (through 2018) • Develop and test alternative prototype passage structures, such as “waterfall” climbing wall concept

Development of LPSs, particularly at Bonneville Dam, has continued since 2008. Since the initial 10 Year Plan was completed, two new LPSs have been installed (one at Bonneville and one at John Day) and one prototype – the experimental North Downstream Entrance LPS at the BON Washington Shore Ladder – was displaced by a new entrance structure that is partially based on LPS design criteria. This new entrance flume structure (see MOA AL 6 below) includes an LPS at the upstream terminus. As with the existing LPSs located in the AWS channels of the Washington Shore and Bradford Island ladders, the purpose of these systems is to guide lamprey out of the main fish ladders and into alternative routes specifically designed for these fish.

Lamprey Passage Structures are known to be effective once lamprey approach them, so improving guidance to the structures can increase overall use (Corbett et al. 2013). USACE and researchers made minor modifications to count station picket leads in an effort to increase guidance to the AWS channel LPSs at Bonneville Dam. These modifications included raising picket leads by up to 1.5 inches at both ladders and installation of a metal ramp at a small step below picket leads at Washington Shore Ladder. Radio-telemetry monitoring in this area has been limited in recent years, but initial results suggested that raising picket leads increased use of the LPSs (Clabough et al. 2011b).

U.S. Army Corps of Engineers anticipates continuing the development of new and existing LPSs through 2018. In addition to extensions and additions of collection ramps to existing structures as described below, we intend to continue experimentation with new lamprey passage concepts, such as a 90-degree vertical “waterfall” structure that would allow lamprey in a serpentine weir section at BON to get over a wall to the preferred AWS channel (then to the existing LPS). USACE-funded researchers have continued to modify the existing systems. Of particular interest to USACE and regional partners is development of effective counting systems to facilitate accurate escapement estimates. Researchers have continued to experiment with various techniques, including mechanical and video counters, with mixed success. This effort will continue through 2018, possibly with mechanical and electrical engineering support by USACE personnel.

1. Bonneville Cascades Island Ladder Entrance LPS

Entrance modifications completed in 2009 (see MOA AL 6) included installation of an LPS immediately upstream of the fishway entrance (Figure 8). The design concept was to use artificial rock structures (bollards) and plating installed on the fishway floor to guide lamprey to the new LPS collection ramp. This LPS is routed to the Spillway forebay, initially to a temporary trap/haul holding tank but now to an outfall directly into the forebay. Researchers have continued to modify discharge in an effort to determine the optimum flow setting for the system.

The overall entrance improvements evaluation results are described elsewhere, but it is important to highlight that lamprey use of the Cascades Island LPS steadily increased from 2009 to 2012, adding further credence to speculation that there is a natural "seasoning effect" for new structures (Figure 5, Corbett et al. 2013). Relative passage via this LPS was very high in 2012, representing 13.4% (n=2,475) of the total daytime count at Bonneville Dam. Given the small cross-sectional area of the LPS collection ramp in the tailrace area and the vertical height that lamprey using this structure must ascend, USACE is encouraged by the initial success of this structure and believes that the design concept can be applied to the same lamprey passage bottleneck areas in other ladders. This may be one of the few structural options for improving lamprey passage in the lower reaches of fishways (transition pools, collection channels, and junction pools), where passage efficiency is typically poor.

The structure was extended to the forebay and converted to a fully volitional passage system in 2013 and preliminary passage estimates suggest the modifications (and perhaps new "unseasoned" materials) may have reduced relative passage via this route in 2013. Pending prioritization, USACE intends to add an additional collection ramp to the system, on the south wall of the Cascades Island entrance/Spillway monolith.

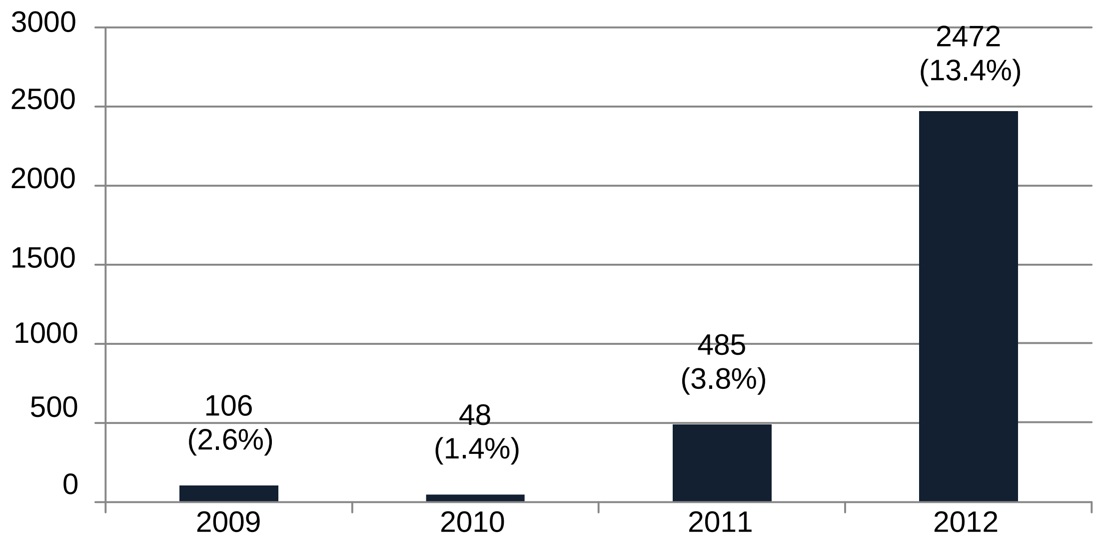

Figure 5. Number of lamprey captured in holding tank at terminus of the Cascades Island Ladder LPS (with % of total Bonneville Dam daytime window count for reference).

2. Bonneville Washington Shore North Downstream Entrance Flume System LPS

The BON Washington Shore Lamprey Flume System (LFS) was installed in winter 2012-13, with further modifications and repairs slated for winter 2013-14 (see MOA AL 6). Initial lamprey use of the LFS and connecting LPS was promising (Figure 6), structural and design issues limited operation of the system in 2013. Plans are underway to evaluate the system in 2014-2015, after some of the design flaws have been addressed.

Pending 2013-2015 evaluation results, funding availability, and prioritization, USACE intends to extend this LPS to the forebay and add additional collection ramps that would connect to the primary system. These auxiliary ramps would be located in key bottleneck areas, such as the transition pool and immediately downstream of the count station (downstream of the serpentine weir section).

A. B. C.

Figure 6. Photos of adult Pacific lamprey using the Bonneville Washington Shore LFS (A) and LPS (B,C) in 2013. Design and installation flaws in the upwelling box immediately upstream of the ramp shown in photo C may appeared to cause a bottleneck in passage in the prototype LPS in 2013.

3. John Day North Ladder Entrance LPS

Entrance modifications at the JDA North Ladder completed in 2013 included installation of an LPS immediately upstream of the new variable width weir (Figure 7). This configuration is very similar to the one evaluated at BON Cascades Island Ladder, though with the LPS terminating at a holding tank on the tailrace deck. First year (2013) operations were somewhat limited, but were encouraging. Between 19 July and 10 September, a total of 62 lamprey were collected from the LPS holding tank, representing 1.2% of total day and night count window passage at JDA North Ladder during this period (N=5,006). Since there appears to be a “seasoning” effect with new structures, we anticipate that collection numbers will improve in coming years.

Pending 2013-2015 evaluation results, funding availability, and prioritization, USACE intends to extend this LPS either to the forebay or to the overflow section of the ladder (where passage efficiency is relatively high).

Figure 7. Photo of John Day North Ladder entrance LPS, which was installed during the 2012-2013 winter maintenance period as part of the broader entrance improvements at this fishway. In operation between 19 July and 10 September, a total of 62 lamprey were collected from the LPS and released above the dam.

MOA AL 5: EVALUATE REDUCING ENTRANCE FLOWS AT NIGHT TO ASSIST LAMPREY ENTRANCE PASSAGE; AND AS WARRANTED, EXPAND THROUGH FCRPS MAINSTEM DAMS.

1. Nighttime Entrance Velocity Reduction Evaluation: Bonneville Dam (MOA AL 5)

A potential solution to poor entrance efficiency (entrance : approach ratio) is to lower ladder entrance velocities at night when lamprey are most active and salmon are less active. In 2007 and 2009, USACE-funded researchers conducted tests using blocked treatments of standard (target of >6.5 ft · sec^{-1}; 1.5 ft of head) versus lowered night-time entrance conditions at the four main BON Washington Shore Ladder entrances (Johnson et al. 2009). By reducing the volume of water added into the lower ladder through the AWS, entrance head was reduced to 0.5 ft and velocities to around 4 ft/sec between 10:00 PM and 4:00 AM one night of each block. By monitoring radio-tagged lamprey, the utility of using lowered velocities to improve fishway entrance rates for adult lamprey was evaluated. Entrance efficiencies for all entries and approaches were significantly different between treatments: 34% at low velocity, 24% at normal velocity and 10% with fish pumps in standby to float trash ($P = < 0.001$). Overall entrance rates at the north entrances were lower than at the south entrances and other entrances along the collection channel, suggesting that differences in tailrace conditions or other orientation/attraction cues also affected entrance attraction and success between locations. For example, entrance velocities vary and are typically higher at the north entrances than at the south.

While there was a net benefit to lamprey passage at the Washington Shore Ladder at BON, resulting in a permanent change in nighttime operations at the dam, generalizing these results to other fishway systems is not recommended. Each fishway is configured somewhat differently and there is a risk of causing lamprey passage delays or worse, given observed negative effects on fishway attraction flows. Reducing AWS discharge to achieve low entrance velocities may help lamprey that have approached an entrance, but may have a deleterious effect on attraction to the ladder or to hydraulic cues inside the fishway.

2. Nighttime Entrance Velocity Reduction Evaluation: McNary Dam (MOA AL 5)

In 2009 and 2010, MCN South Ladder entrance velocities were manipulated using a different methodology than that used at BON. Instead of reducing AWS flow, entrance weirs were lowered, with no reduction in ladder auxiliary water volume thus reducing entrance velocities without a reduction in entrance water volume or fishway attraction water. Radio-telemetry was used to evaluate impacts on passage metrics, particularly entrance efficiency and overall dam passage efficiency. It should be noted that small run sizes in both study years and difficulties trapping fish at McNary dam precluded tagging an adequate sample size of adult fish (Boggs et al. 2010).

Results indicated no significant differences in frequency of approach or entry during control versus reduced velocity treatments (P-value range 0.41-0.61). There was no evidence of a strong negative effect on adult lamprey entrance efficiency or ladder passage. Thus, the results suggested a neutral impact on lamprey passage.

Although the results were ambiguous, USACE decided to implement this nighttime operation, with the assumption that based on lamprey swimming behavior, there is likely a small net ladder entrance passage benefit. Concerns have been raised about the extra wear and tear the mechanical systems supplying water to the lower ladder diffusers by repeatedly changing their operation but such operations may be a short term alternative until major entrance modifications can be implemented, Future entrance modifications will provide a low entrance velocity lamprey passage structure and, depending on the results of passage studies for this structure, USACE can discontinue lowering the entrance weirs at night which addresses O&M concerns.

MOA AL 6: COMPLETE KEYHOLE ENTRANCES CASCADE ISLAND 2009 AND JOHN DAY NORTH 2010/2011 THEN IMPLEMENT AS WARRANTED THROUGH FCRPS MAIN STEM DAMS.

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018

• BON Cascades Island Ladder Entrance modifications (2008-09)
• BON Washington Shore Ladder – North Downstream Entrance (NDE) Lamprey Flume System (2012-13)
• JDA North Ladder Entrance modifications (2011-13)
	• Modify and improve BON Washington Shore NDE Lamprey Flume System structure and operations, as needed (2013-14, 2014-15)
	• Install prototype deep fishway entrance passage structure at MCN Oregon Shore Ladder (SFE2) (2013-14)
	• Pending success of MCN Oregon Shore deep fishway entrance prototype, install similar system at ICH South Ladder (SFE1) (2016-17)
	• Modify entrance weir crests to allow attachment and improve fishway access:
	  • BON Bradford Island (2015-16)
	  • BON Washington Shore (2014-15)
	  • TDA North and East (2017-18)
	  • JDA South (2016-17)
	  • MCN Oregon Shore (2016-17)
	  • MCN Washington Shore (2016-17)
	  • ICH North and South (2017-18)
	  • LMN North and South (2017-18)

1. Bonneville Cascades Island Fish Ladder: Entrance Modifications and LPS

One approach to improving entrance efficiency is to modify the existing entrance weir and floor to reduce velocities to make it easier for adult Pacific lamprey to enter the fishways (**MOA AL 6**). At entrances to fishways, structures can be installed to reduce floor velocities and to guide lamprey to LPSs. In the FCRPS, this concept was first applied at BON Cascades Island Fish Ladder (CI; 2009), with the intent of using the configuration as a prototype for modifications elsewhere, such as the JDA North Ladder entrance (2010-2013).

Specific changes to the CI Ladder entrance area included (Figure 8): (1) the entrance weir shaped to accommodate many different tailrace elevations with variable width and rounded edges in order to facilitate lamprey movement, (2) structural elements (bollards) added to the floor just inside the entrance to simulate a rock floor that reduces velocities for lamprey to move through, which were tested in the research flume, and (3) floor structure configured to lead lamprey to an LPS located upstream of the entrance.

A combination of radio-telemetry and a half-duplex PIT-tag (HD-PIT) antenna array was used to evaluate passage of lamprey and spring-summer Chinook salmon at the modified entrance in 2009 and 2010; video and other tools were used to supplement this information. Overall, the modifications appear to have resulted in net benefits to lamprey passage and a neutral effect on salmon passage. Lamprey entrance efficiency at the CI Ladder improved after the modifications, while the changes may have resulted in allowing more individuals to move freely in and out of the fishway entrance and tailrace, increasing fishway exit ratios and lengthening passage times (Clabough et al. 2011a). Notably, lamprey passage success at the new CI Ladder LPS improved each year from 2009 to 2012 (Corbett et al. 2013).

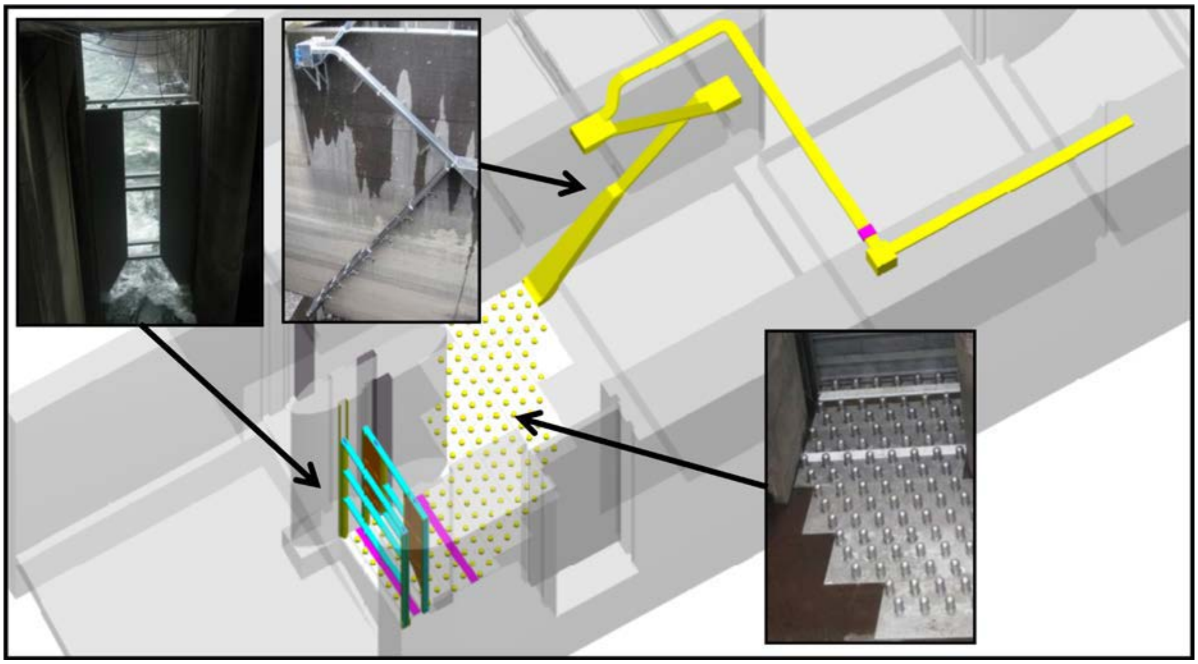

Figure 8. Modifications made at BON Cascades Island Fish Ladder included a fixed (variable width) entrance weir with rounded edges, velocity reducing structures along the fishway floor, and an LPS that leads to the forebay of the dam. Studies suggest a net benefit to lamprey passage and a neutral affect on salmon passage.

2. John Day North Fish Ladder: Entrance Modifications and LPS

In 2013, USACE completed modifications intended to increase the entrance discharge and improve the overall performance (for salmon and lamprey) of the lower ladder section of John Day North Fish Ladder including entrance, AWS, transition channel, and lower fishway weirs. A primary feature of the modifications is replacement of two existing 12-foot-wide modulating entrance weirs by a single fixed entrance weir similar to the design to the modification described for the Bonneville Cascades Island Ladder entrance.

Design features include: (1) the entrance shape accommodate the specific flow requirements at the different tailrace elevations with the variable width, (2) entrance weir edges have a 4-inch radius to facilitate lamprey attachment, and (3) bollard field on floor to reduce velocities, provide velocity refuges, and attachment points for lamprey. As with Cascades Island entrance improvements, the bollard field leads lamprey to an LPS (see MOA AL 4). In addition, diffuser gratings were replaced with ¾ inch grating (see MOA AL 7), and lower ladder (transition pool) weirs were removed and AWS pumps replaced to increase the hydraulic signature of the ladder.

Construction for this project occurred in two winters. For the 2012 study year, completed features included the variable width entrance weir, bollard field, and removal of lower ladder weirs. While no radio-telemetry evaluation was completed in 2012, a DIDSON acoustic camera was used to evaluate lamprey behavior in the entrance area and elsewhere. Results indicated that lamprey actively used the bollard field to navigate the entrance area and that they free-swam in the water column in the relatively low velocity areas of the transition pool section upstream of the entrance (Johnson et al. 2013).

Additionally, there appeared to be segregation of lamprey and sturgeon in the lower fishway, which may suggest predator avoidance by lamprey. Limited DIDSON observations continued in 2013, along with a PIT evaluation (antennas were integrated into the entrance/bollard field area), but results were not available at the time this report was completed. A radio-telemetry study is planned for 2014.

3. Washington Shore Ladder - North Downstream Entrance Lamprey Flume System and Lamprey Passage Structure.

The Washington Shore Fish Ladder was selected as a priority modification for lamprey because radio-telemetry evaluations have shown that the Powerhouse 2 fish ladder entrances had the most consistently poor entrance efficiencies, while seeing the greatest number of lamprey approaches. Additionally, because Bonneville is the first dam fish must pass when traveling upstream, USACE and our tribal partners recognized the importance of improving lamprey passage at the dam.

Because the existing fish ladder entrance selected for modification (the North Downstream Entrance) was considered too narrow to allow modifications for lamprey passage without potentially hindering salmonid passage, an alternative strategy was employed. The prototype LFS is intended to provide a kind of bypass around the fishway entrance and other troublesome fishway features (transition pool, serpentine weir sections, etc). The flume features two entrances (one shallower and one deeper) that span the width of the conventional fishway entrance and attraction flow will be provided by a gravity-fed water supply pipe (Figure 9). Lamprey that enter the flume from either entrance will make a gradual ascent for about 60 meters and then begin a similar ascent as in existing lamprey passage systems. The flume connects to an LPS that terminates (temporarily) in a collection tank at the tailrace deck. From here, researchers transport lamprey to the forebay for release. If the LFS is successful, as with the Cascades Island Ladder LPS, the Portland District intends to extend the LPS to the forebay so the lamprey will be able to reach the forebay waters without human intervention.

Installation of the LFS and connecting LPS was completed in Spring 2013, but structural and design issues prevented full operation 2013. Initial monitoring suggested that the LFS and LPS were effective in attracting and guiding lamprey to the top of the system, but minor design and fabrication flaws in the upper sections of the LPS may have created a bottleneck that lead to several lamprey mortalities in the system. Some design issues were addressed during the 2013 season, while others will be addressed during the 2013-14 in-water-work period. The structural supports for the LFS were also found to have problems; efforts are underway in Fall 2013 to ensure structural integrity.

Several HD-PIT antennas are integrated into the LFS and LPS, and plans are underway to use DIDSON monitoring, HD-PIT, radio-telemetry, and collection numbers to evaluate lamprey passage through the system in 2014 – 2015. It should be noted that although the basic concept of the LFS could be applied to other fishway entrances, overall cost and lack of available screened water would make it unlikely for this particular design to be applied elsewhere in the FCRPS.

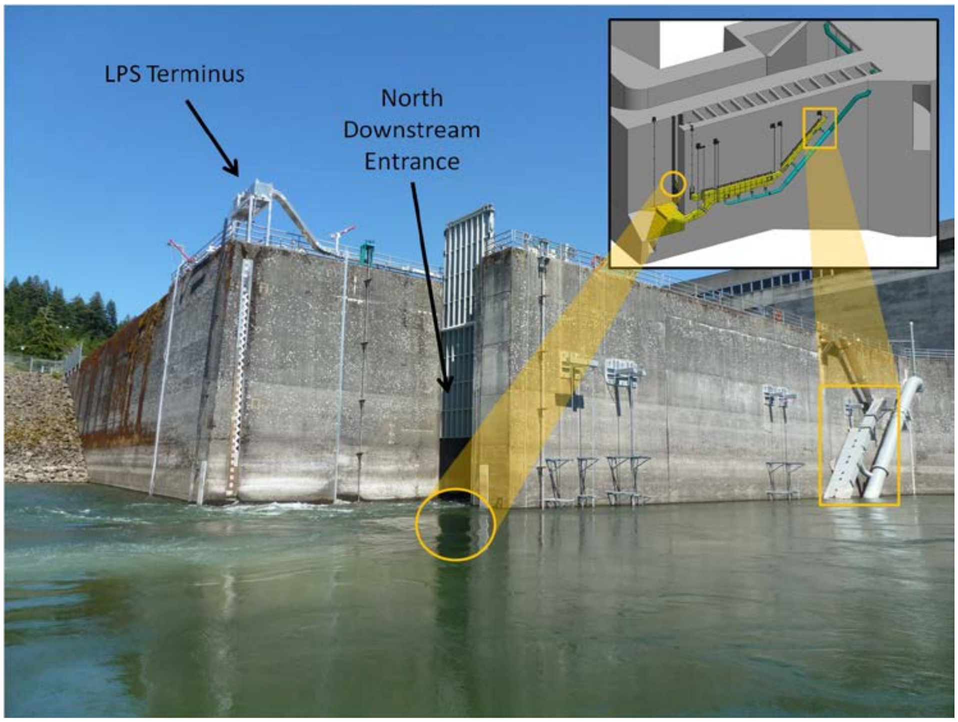

Figure 9. Bonneville Washington Shore Lamprey Flume System (LFS). The LFS flume (yellow in drawing) guides lamprey to a Lamprey Passage Structure (LPS) and holding tank on the tailrace deck (not shown in drawing). Screened water is provided via the gravity water supply pipe.

MOA AL 7: INVENTORY ALL PICKETED LEADS, FISHWAY CRACKS, BLIND OPENINGS AND LADDER EXITS. BEGIN REPLACING EXISTING GRATING WITH NEW 3/4" GRATING IN MOST IDENTIFIED PROBLEM AREAS.

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018

• Annual fishway maintenance inspections
• BON WA Shore count station picket leads modified to encourage lamprey use of LPS and improve accuracy of counts (2010-11)
• JDA North Ladder exit section diffuser grating replaced with ¾-inch grating (2009-10)
• JDA North Ladder lower ladder diffuser grating replaced with ¾-inch grating (2012-13)
• Picket leads at all USACE dam ladders along the lower Columbia and Snake rivers lifted by 1.0 to 1.5 inches (2010-2013)
• JDA South count station lamprey collection and counting structure (2012-13)
• Lamprey orifices installed and evaluated:
  • MCN Oregon Shore (2009-10)
  • ICH North and South (2011-12)
  • LMN North and South (2011-12)
  • LGS (2012-13)
	• Continue annual fishway maintenance inspections
	• Modify BON Bradford Island count station picket leads to encourage lamprey use of LPS and improve accuracy of counts (2013-14)
	• Use picket leads with 0.75-inch openings or smaller at Cascades Island/UMT junction area (2013-14), the Washington Shore junction pool wall diffuser (2016-17), and the JDA South SE1 wall diffuser (2016-17), to block access to problem areas
	• Install new LPSs at BON Bradford Island (2017-18), Cascades Island (2016-17) and Washington Shore (2016-17) to attract lamprey to alternate passage routes in junction/transition/turning pools of lower ladders
	• Pending success of JDA South Ladder Lamprey Collection and Counting Structure, install similar systems at JDA North (2015-16) and TDA East ladders (2015-16)

• Lamprey orifices installed and evaluated: • MCN Oregon Shore (2009-10) • ICH North and South (2011-12) • LMN North and South (2011-12) • LGS (2012-13) • LGR (2012-13, 2013-2014)	• Evaluate passage impacts of blocking lamprey access to areas behind picket leads to improve counting (through 2018) • Install and evaluate lamprey orifices in ladders, as appropriate: • BON Bradford Island (2015-16) • BON Washington Shore (2016-17) • MCN Washington Shore (2015-16)

Due to their relatively small girth, eel-like body shape, and anguilliform swimming behavior, adult Pacific lamprey are able to access areas of fishways that adult salmonids cannot. Conversely, these characteristics can be utilized to attract them to LPSs and other lamprey-specific passage features without impacting ESA-listed salmon. In drafting the 2008 Columbia Basin Fish Accords, USACE and our tribal partners agreed that identifying and addressing potential fishway features that might attract and entrain lamprey was an important task. Most specifically, USACE agreed to consider phased replacement of existing 1-inch opening diffuser grating with smaller ¾-inch diffuser grating to exclude lamprey from AWS systems.

1. Picket Leads

Picket/picketed leads consist of panels of vertical bars and at FCRPS fishways, are used to guide upstream-migrating fish past count windows (Figure 10). In-ladder lamprey trapping efforts and annual fishway dewaterings showed that lamprey regularly accessed the areas behind picket leads. This can confound lamprey escapement estimates, but it also provides lamprey with a lower velocity alternative to count station slots. Based on previous studies, it is advisable to use openings between 1 and 1.5 inches to facilitate lamprey passage without impeding salmon passage *or* 0.75 inches to *exclude* lamprey and salmonids (Moser et al. 2008, Clabough et al. 2011b, Clabough et al. 2012 letter report). The current NOAA guideline for picket lead bar spacing is 1 inch, so consultation with NOAA Fisheries and other regional managers is necessary when picket lead spacing is altered.

In an effort to provide a contiguous surface along the bottom of the fishway and to improve access to the area behind the picket leads, recent improvements to the JDA North Fish Ladder (JDAN) count station area included lifting picket leads by 1 inch.

In May 2010, 2.5 cm (1 inch) spacers were installed at the base of picket leads at the Bonneville Dam Washington Shore Fish Ladder count station to evaluate whether lifting picket leads could improve access to and use of the Lamprey Passage System (LPS) located in the AWS channel upstream of the picket leads (Corbett et al. 2013). Field measurements the following winter indicated that the gaps at the base of the lead varied and were as high as 3.8 cm (1.5 inches). Lifting the picket leads resulted in an immediate increase in use of the Washington Shore LPS and an overall improvement in total dam passage efficiency at Bonneville Dam in 2010 (Clabough et al. 2011a, Corbett et al. 2013). As a result of this investigation, picket leads at fish ladder count stations of all USACE dams along the lower Columbia and Snake rivers were lifted by 1 (Bonneville Dam) to 1.5 (all others) inches to provide migrating lamprey with improved access to all count station picket lead areas. Picket leads at JDAS were lifted by 1.5 inches in winter 2011.

In summer 2011, several sockeye salmon (*Oncorhynchus nerka*) were found to be trapped behind picket leads at the Bradford Island Fish Ladder of Bonneville Dam. It is believed that the fish accessed the area as a result of the combination of installation of 1 inch spacers on the bottom of the picket leads and the uneven floor surface at that location. As a result, the spacers were immediately removed at the Bradford Island *and* the Washington Shore ladders and in winter 2011-2012, USACE made modifications to the picket leads and floor sill at Bradford Island to ensure that the gaps were no larger than 1 inch. Similar modifications to the BON Washington Shore Ladder picket leads were made in winter 2012-13. Observations by project biologists and results from a video evaluation indicated that despite a record sockeye salmon run in 2012, no sockeyes were observed behind picket leads at Bradford Island Fish Ladder (Clabough et al. 2012 letter report).

Raising picket leads by up to 1.5 inches may increase passage options for lamprey, but by altering the existing configuration, USACE and our partners expect that this has a detrimental effect on the accuracy of count window escapement indices. An alternative approach under discussion is to block lamprey from areas behind picket leads, thereby forcing them to pass via count slots. This approach has been implemented at PUD-operated dams in the mid-Columbia region, though the exact impacts on lamprey passage are poorly understood. Velocities in count slots vary but do not approach or exceed barrier velocities for lamprey (Keefer et al. 2010). USACE intends to test this configuration on a trial basis at a single ladder to evaluate impacts on passage.

Picket leads may also be used to redirect lamprey away from known problem areas. At BON Cascades Island Ladder, picket leads (1 inch openings) are used to guide fish to the Upstream Migrant Channel (UMT), which leads salmon and lamprey through Powerhouse 2 to the Washington Shore Ladder. The exit section of the Cascades Ladder (upstream of the junction with the UMT) is only used to pass fish during brief transitions in operations when the Bradford or Washington Shore ladders are taken out of service for maintenance. However, adult lamprey are known to accumulate in the upper ladder, particularly in the AWS channel, which continuously provides attraction flow to the ladder sections UMT junction area below. This accumulation of lamprey (Figure 11) can be addressed by either blocking access (0.75 inch picket lead openings) or provision of an LPS in this section. At this time, USACE intends to block access to the BON Cascades Island AWS Channel, guiding all fish to the Washington Shore Ladder.

Figure 10. Dewatered count station at The Dalles Dam East Fish Ladder, facing upstream. Picket leads (at right) guide fish to the count slot (left). Picket lead panels have been elevated off the fishway floor by 1 to 1.5 inches to offer lamprey an alternative passage route.

Figure 11. Adult lamprey congregate in the AWS channel of the BON Cascades Island Ladder. Photograph was taken during a mid-season dewatering event in 2013. In winter 2013-14, USACE intends to install 0.75-inch opening picket leads downstream of the channel to prevent lamprey from accessing this dead end channel.

2. Adult Lamprey Collection Behind Picket Leads

In response to requests by the Yakama Nation and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) regarding impacts of improvements at JDA North Ladder on trapping efficiency at John Day Dam, USACE designed and build a prototype lamprey collection and counting structure at the JDA South Ladder count station in winter 2012-13 (Figure 12). Lamprey approaching the count station picket leads are guided through the system into a trap box. When not actively trapping, a door/ramp on the box may be left in an open position, allowing lamprey to exit back into the fishway upstream of the count station. Although a more permanent counting system is in development, a video camera is used to count lamprey entering the trap box. It should be noted that picket lead spacing was *reduced* to ¾-inches, except for the base of the leads (1.5 inches) to force all picket lead-passed lamprey to enter the collection and counting system. In 2013, 100 lamprey were collected in the trap box and an unknown number of lamprey passed through the system in bypass mode (analysis is ongoing).

Minor modifications to the JDA South Ladder structure are planned for winter 2013-14; pending success of this prototype trap, feasibility of applying the concept elsewhere, and prioritization by Accord partners, USACE proposes to install a similar system at JDA North and/or TDA South ladders.

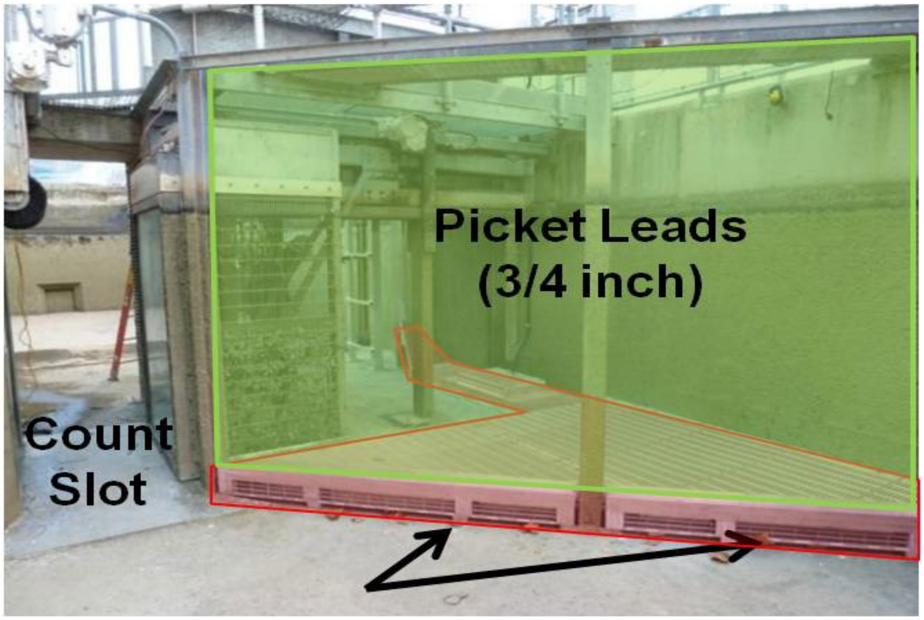

Figure 12. John Day South Fish Ladder Lamprey Collection and Counting Structure. This prototype system was installed during winter 2012-13. Picket leads (removed in photo) spacing was changed to ¾ inch to force lamprey approaching this area to use the collection structure. Lamprey are then guided to a trap box (not shown) for collection or bypass back to the ladder.

3. Auxiliary Water Supply Channels and Cul-de-Sacs

Large numbers of Pacific lamprey searching for a way over a dam may avoid the higher velocity areas in fishways and move into and congregate in dead-end side channels at dams. Many of these fish may never pass the dam. This behavior can be managed either by blocking off the entrance to these dead ends by installing smaller gap-picket leads or screens, or this behavior can be exploited to improve passage by the deployment of a LPS.

Installation of LPSs in the AWS channels at Bonneville Dam has proved very successful at passing large numbers of Pacific lamprey (see MOA AL 4). Similarly, the Cascades Island ladder entrance LPS shows promise in diverting lamprey away from the large turning pool in the lower ladder (Figure 13).

Figure 13. The large turning pool in lower Cascades Island Ladder and in similar ladders may cause migration delays for Pacific lamprey. The new Cascades Island entrance LPS (right) diverts some lamprey out of the main ladder and into an alternative system.

4. Diffuser Grating

Fish ladders of the lower Columbia River dams typically have diffuser systems that supply auxiliary water to maintain salmon hydraulic criteria in the ladders under varying forebay and tailwater elevations. These AWS feed water to bubbler beams that move flow through steel gratings with 1-inch openings. The gratings were designed to keep adult salmon from entering the AWS system. When adult lamprey encounter the diffuser grating, they may go through the grating into the underlying chamber and become trapped. This is particularly true when the fishways are dewatered for inspection and repair. Historically, up to several hundred stranded lamprey have been found trapped in these chambers and had to be removed by hand. Improvements to dewatering and salvage operations that include ensuring sufficient time and equipment to handle fish and better management of draining and pooling of water to assist with the logistics have been established to reduce the numbers of lamprey likely to move through the gratings but strandings and mortalities still occur.

Evaluations in the laboratory and in the JDA North Fish Ladder showed that reducing the grating size openings from 1 inch to 0.75 inch would basically eliminate lamprey passage through the gratings (Moser et al., 2007). A 0.75-inch gap size for new diffuser and intake gratings has been adopted as the new criteria for the lower river by the Fish Passage Operations and Maintenance Team. Even though lamprey lose girth as they migrate upstream, these new criteria should be effective as the critical dimension appears to be the size of the head which does not vary as girth changes (M.L. Moser, NMFS, personal communication).

A letter report was completed by USACE in May 2008, which determined that the diffuser gratings in the fish ladders should be replaced with 0.75-inch powder coated galvanized steel grating or best material available. (A companion report identifying issues, priorities, and costs for the McNary and Snake River projects is currently under development.) The recommended grating material is similar to the existing diffuser grating porosity; thus, extensive hydraulic analysis was not needed. The trash racks in the fish ladders also need to be upgraded to match the 0.75-inch gap grating to avoid debris issues underneath the diffuser gratings. This in turn, may result in needs to improve trash rack cleaning systems. Replacing the diffuser gratings at many ladders will also require the replacement of the grating support systems with stainless steel to avoid corrosion and because many of the diffuser grating support systems were not designed to carry the required structural loads for walkways and platforms, and have to be redesigned to meet current standards.

Existing grating will be replaced with the new 0.75-inch opening grating as funding and prioritization allows. Generally, the cost of the required structural changes relative to other adult lamprey passage problems and solutions has made grating replacement a relatively low priority for USACE and our tribal partners. However, major modifications to the JDA North Fish Ladder exit section and lower ladder included installation of 0.75-inch grating (Figure 14).

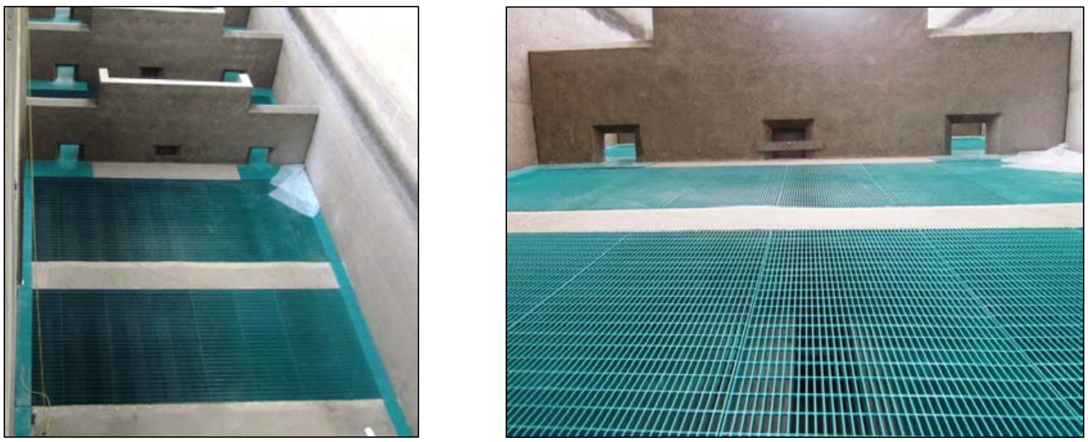

Figure 14. Modifications to the JDA North Ladder included installation of lamprey-friendly 0.75-inch opening diffuser grating (powder-coated in green). The new grating prevents lamprey from infiltrating the AWS system of the ladder. Other lamprey improvements here include removal of obsolete overflow weirs, which may have negatively affected attraction flow, and installation of plating in key areas (visible in photo) to allow attachment.

5. Lamprey Orifices

During discussions in the early development stages of the 10 year plan, some potential passage problems were identified. One of those potential problems was the elevated passage orifices that existed in most of the NWW district dams. These elevated orifices were designed for salmonid passage, but posed possible velocity and right-angle corner problems, i.e., lamprey could not use the attach and burst swim strategy to overcome this passage route. Other routes were available, such as going over the weir wall near the surface or a vertical slot not much different than the elevated slots. Two possible solutions were identified, either provide a ramp to the elevated orifice or provide a floor orifice that aided the attach and burst swim strategy.

In late 2009, the Walla Walla District made modifications to the tilting weir and diffuser grating sections in the south ladder at McNary Dam in an effort to improve passage and reduce delay of lamprey. The tilting weir section is comprised of a series of tilting weirs with elevated fish passage orifices located several feet above the fishway floor. The purpose of these orifices is to allow passage of migrating salmonids. Modifications to this area included the installation of lamprey orifices (measuring 3 inches tall by 18 inches long) cut flush to the fishway floor at seven stem walls supporting the tilting weirs; a total of 14 new lamprey orifices installed, two per tilting weir. Initially these orifices had the ability to be opened and closed with a sliding gate which was operated by a turnhandle located on the ladder walkway, and the orifices are lined with metal for hydraulic reasons and to also serve as lamprey attachment points. Metal plating was installed around the elevated salmon orifices, of the tilting weir section, to provide a continuous surface for adult lamprey to attach and rest before attempting to pass through the orifice (Figure 15). In

addition to the lamprey orifices, metal plating was installed over the top of three diffuser gratings to aid in lamprey attachment and passage through the lower section of the ladder.

Figure 15. Newly installed lamprey orifice in the MCN Oregon Shore Fish Ladder, tilting weir stem wall (lower left). Additionally, steel plating was installed around the elevated orifices to provide attachment surfaces for adult lamprey.

While installation of these orifices was intended to improve lamprey passage, concern was the orifices may delay passage or otherwise harm migrating adult stocks of salmon, steelhead. The use of underwater video monitoring was proposed as a non-invasive means of studying the behavior of spring/summer/fall Chinook, steelhead, Sockeye, and shad. Low-light video cameras were used so both day and night -time monitoring of lamprey and adult salmonids behavior could be accomplished.

Lamprey used the new passage routes with more lamprey observed in the video monitoring than were counted passing through the count slot (Eder et al. 2011). This was credited to lamprey passing through the picketed lead panels undetected and some milling behavior on the part of the lamprey. It is not uncommon to see lamprey moving both upstream and downstream through all monitored passage routes. Salmonids were seen in the vicinity of the lamprey orifices, on the recorded videos, but attempted passage was limited to a total of eight salmonids. Because of the surprising number of lamprey identified using the new orifices and the relative few salmonids attempting to use the orifices USACE and tribal partners agreed that this was a net benefit for lamprey passage through the control section of the fish ladder. Additionally, the slide gates were removed the next dewatered ladder period due to maintenance problems and the reduced likelihood that the orifices posed a risk to salmonids

Based on the identified success of the lamprey orifices in the south ladder at MCN, the Walla Walla District moved forward with lamprey orifice installation in the adult ladders at all of the lower Snake River dams between 2011-2013. During the 2013-2014 dewatered ladder period, installation of the lamprey orifices will be completed in the LGR adult ladder. Because there were a few salmonid interactions with the initial lamprey orifice installation at MCN South, USACE and tribal partners agreed that reducing the size of the orifices slightly would be not harm lamprey passage while reducing the risk to salmonids. The dimensions of the lamprey orifices at all of the lower Snake River dams are 2.5 inches tall by 16 inches wide.

MOA AL 8: ROUND SHARP CORNERS AS WARRANTED.

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018

• BON Cascades Island entrance weir replaced with variable width weir with rounded edges; bulkhead slot filler with rounded edges installed (2009-10)
• BON WA Shore – Installed ramp to base of picket leads to improve access to LPS (2010-11)
• TDA East – Installed ramps to raised orifices (2011-12)
• TDA North – Rounded raised weir orifices in lower ladder (2009-10)
• JDA North – New upper ladder modifications included rounded vertical slot weirs and orifices (2009-10)
• JDA North entrance weir replaced with variable width weir, with rounded edges (2011-12)
• Removed sharp edges in count station areas of MCN (2009-10), ICH (2011-12), LGO (2011-12)
• Installed ramps to raised lamprey orifices at LMN North and South (2011-12)
• Installed diffuser plating throughout system to allow attachment:
  ◦ JDA North (2009-10, 2012-13)
  ◦ MCN Oregon Shore (2009-10)
  ◦ ICH North (2011-12)
  ◦ LGO (2012-13, 2013-14)
  ◦ LGR (2012-13, 2013-14)
• Included 4-inch minimum radius in new Willamette River Project ladder improvements
	• Modify entrance weir crests to allow attachment and improve fishway access:
	  ◦ BON Bradford Island (2015-16)
	  ◦ BON Washington Shore (2014-15)
	  ◦ TDA North and East (2017-18)
	  ◦ JDA South (2016-17)
	  ◦ MCN Oregon Shore (2016-17)
	  ◦ MCN Washington Shore (2016-17)
	  ◦ ICH North and South (2017-18)
	  ◦ LMN North and South (2017-18)
	• BON Bradford Island (2015-16) and Washington Shore (2016-17) serpentine weir modifications may include rounded corners, pending hydraulic and structural review
	• Modify (ramp or round) wall upstream of JDA South entrance SE1 (2017-18) and at 6- inch rise in floor in upper ladder (2013-14).
	• Install diffuser plating to provide attachment surfaces in fishways:
	  ◦ BON Washington Shore (2014-15)
	  ◦ BON Bradford Island (2016-17)
	  ◦ TDA East (2013-14)
	  ◦ TDA North (2017-18)
	  ◦ JDA South (2013-14)
	  ◦ MCN Washington Shore (2016-17)

Adult Pacific lamprey utilize a "burst-and-attach" strategy when navigating high velocity areas. By attaching to substrates with their oral discs, then bursting forward before reattaching, lamprey are able to ascend complex structures, such as natural waterfalls and many fishway structures. Sharp corners and edges are common to many fishway features, particularly overflow, vertical slot, and modulating entrance weirs and bulkhead slots that are ubiquitous in USACE dam fishways along the lower Columbia and Snake rivers.

1. Rounding Corners of Weirs and Other Structures

After the installation of rounding modifications to the Bonneville spillway entrance bulkheads in 2000, there was a corresponding small increase in passage efficiencies (44%-57% to 60%-65%) at those entrances from 2000-2002 (see Table 2 in Moser et al. 2003). The passage efficiency for the collection section of the ladders just above the entrances increased even more for those same years (54%-60% to 89%-96%) and may indicate other factors influenced entrance improvements beside the bulkhead shape modifications.

University of Idaho laboratory evaluations of the effectiveness of rounding corners showed a significant relationship between rounding bulkheads and an increase in night-time passage rates in the test flume from 32.5% to 50.8%, and a reduction in passage times from a mean of 3 minutes to 1.4 minutes (see Table 9 and Figure 17 in Daigle et al., 2005). However, these improvements were small when compared to those that occurred when head and velocity were reduced.

Both of these evaluations focused on rounding at entrances where entrance efficiency is low and rejection is high. Researchers emphasized that the entrances should be the priority location to attempt to round structures, and that efforts elsewhere may not be needed. Some areas of the fishways with high velocities and unrounded surfaces, such as the main ladder portion of the Washington Shore and Bradford Island fishways, have good passage times and passage efficiencies of about 90% or better. The serpentine weirs in the exit sections may also benefit from rounding. The installation of the adult fish PIT readers in the top of the fishways included rounding of all corners as a required feature. Rounding of orifices, vertical slots, and variable width entrance weir edges was a design feature in all facets of the John Day North Fish Ladder modifications (Figure 15).

One factor that may be important in determining where rounding may be most useful is the added presence of confusing or alternative flows where high velocities exacerbate the problem. The major locations of passage difficulties at most dams are entrances, transition pools, serpentine weirs, and AWS; all are areas with confusing flows (swirling flows in serpentine weirs, optional flows from diffusers or to the sides of entrances that may be enticing when confronted with high velocity for the major upstream movement).

Lamprey are attracted to high flows as is indicated by their passage distribution relative to flows at Bonneville, but may be searching for the complex structures of a normal river environment to find holdfasts and low flow pockets to work their way over difficult high flow passage areas such as rapids and falls or dams. Dams, typically, do not offer that sort of complexity of options for passage and those that are present, such as moving into lower flow diffuser gratings, can be problematic (see MOA AL 7).

In light of the apparent benefits of rounding surfaces – particularly at fishway entrances – USACE intends to modify modulating entrance weirs to provide rounded weir crests and adequate holdfasts on weir faces. Additionally, new structures will continue to use the minimum 4-inch radius as the standard for weir orifices and vertical slots.

Figure 16. New vertical slot weirs at John Day North Ladder feature rounded (minimum 4-inch radius) edges. Rounded edges help lamprey navigate high velocity and/or high turbulence fishway features.

2. Installation of Diffuser Plating and Ramps

Provision of lamprey holdfasts in fishway structures, particularly in high velocity and/or high turbulence sections, may improve overall passage success (Keefer et al. 2010). Of particular concern are the interfaces between floor diffusers (grating) and overflow weir or vertical slot weir orifices. Lamprey passing through the weir orifices or slots encounter velocities that approach their burst swimming capabilities (Keefer et al. 2010), so plating over diffusers, both immediately upstream and downstream of orifices and along fishway walls, has been implemented at a few dams and plans are underway to install plating at others through 2018 (Figure 17).

A. B.

Figure 17. Plating over diffuser grating and concrete at John Day North Ladder (A) and at Ice Harbor North Ladder (B) provides adult Pacific lamprey with attachment surfaces as they navigate the overflow and vertical slot weir sections of fishways.

Additionally, some weir orifices and other structures are elevated relative to the fishway floor, leaving sharp "steps" within the fishway (Figure 18). USACE contractors and researchers have installed ramps to these elevated passage routes to allow surface attachment. Though the benefits of these small modifications are difficult to measure, USACE and our partners assume there are incremental benefits to passage.

A. B.

Figure 18. Ramp to elevated fishway weir orifice at The Dalles Dam (A) and concrete ramp to elevated orifice at Lower Monumental Dam (B).

MOA AL 9: DEVELOP FEASIBILITY, TECHNIQUES AND PROTOCOLS FOR COUNTING.

COMPLETED ACTIONS: 2009 – 2013	PROPOSED ACTIONS: 2014 - 2018
• Initiated nighttime counting at BON, MCN, and LGR (2009) • Expanded nighttime counting to TDA and JDA (2012) • LPS counting system development (2009-2013) • Evaluated count station picket lead passage enumeration at TDA, JDA, MCN, and ICH (2009-2013)	• Complete development of accurate LPS counting systems (through 2018) • Facilitate agreement with Tribes and other regional partners on long-term lamprey passage estimate priorities, i.e., ladder counts (through 2018) • Evaluate effects of blocking passage via picket leads on passage success; implement as appropriate to improve count estimates (through 2018) • Make minor modifications to count stations, as needed and appropriate, to improve lamprey counting (through 2018)

Pacific lamprey counting at most dams occurs only during daylight hours using tabulation of up and down movements through the count windows in all fishways. Because many lamprey are more active at night and because there are numerous routes available for lamprey to pass dams and not be detected at the count windows (e.g., through picketed leads and trash racks, AWS channel, LPS, and others), existing counts are a rough index of passage. From 2007 – 2013, USACE-funded researchers investigated means of improving escapement estimates at USACE dams along the lower Columbia and Snake rivers using nighttime video counts, lamprey PIT detection, LPS counts, and development of video tools for counting lamprey that bypass count windows via picket leads. More meaningful estimates of passage at key dams will allow better evaluation of the overall population status.

In 2009, nighttime counting at Bonneville, McNary, and Lower Granite dams – considered the key check-in dams for salmon and lamprey passage – was included in the regular count program. In 2012, this effort was expanded to The Dalles, John Day, and Ice Harbor dams to improve escapement estimates through the Lower Columbia reach. Minor structural changes to count stations may be required through 2018 to improve accuracy of lamprey counts. In parallel, researchers investigated non-invasive video and acoustic camera tools for estimating passage via picket leads at several dams. Researchers had some success in developing tools that expedite the lamprey counting process (Thompson et al. 2012). Despite this, the studies suggested that monitoring lamprey passage behind picket leads was infeasible due to cost of maintaining equipment and data and the complexity of covering a relatively large area. As a result, USACE and our tribal partners have begun discussing an alternative approach in which efforts are focused on having accurate escapement estimates only at key dams – Bonneville, McNary, Ice Harbor, and Lower Granite dams, for example. At some fishways (i.e., McNary or Ice Harbor Dams), this may mean experimentation with blocking lamprey access to picket leads, forcing them to pass via count slots. This concept has been applied at PUD dams in the mid-Columbia reach but has not been tested at the FCRPS dams in the Lower Columbia and Snake rivers.

Development of accurate and reliable mechanical or video counting systems for LPSs is ongoing. The sensitive mechanical systems currently used in LPSs at Bonneville Dam and elsewhere in the basin require regular validation and adjustment. Lamprey that pass through the exit chutes of the LPSs actuate a paddle-like door made of perforated metal (Figure 19). This paddle is connected to a counter that generates a digital record of the event. Depending on the counter and overall passage activity, lamprey may be over-or under-counted. USACE will continue to collaborate with researchers from NOAA Fisheries on this project and will continue to work on communicating error-checked LPS counts to the region as part of our broader fish count program. USACE intends to have each LPS include fully functional counting systems by 2018.

Figure 19. Exit chute counting mechanism on BON Washington Shore AWS Channel LPS. Lamprey exiting the system actuate the perforate plate paddle, which is connected to a digital counter. Counting systems are still in development.

JUVENILE LAMPREY PASSAGE

INTRODUCTION

Relative to adult Pacific lamprey, downstream migration and dam passage of juvenile Pacific lamprey is poorly understood, though some studies have provided some insight regarding relative route use, screen impingement, and potential turbine passage effects. USACE conducted studies on downstream juvenile Pacific lamprey passage from 2000 to 2002. Based on fyke net evaluations of run-of-the-river fish at John Day, McNary, Bonneville, and other dams, the majority (> 70%) juvenile lamprey appeared to move downstream low in the water column under the turbine intake screens of bypass systems installed for salmonids at USACE dams (BioAnalysts Inc. 2000; Moursund et al., 2003; Monk et al., 2004; Moursund et al., 2006). This results in the majority of juvenile lamprey tending to pass the dams through the turbines when they encounter a powerhouse. USACE funded laboratory studies with Pacific Northwest National Laboratory that demonstrated juvenile lamprey unlike juvenile salmon were not injured or killed in test chambers by changes in pressure and shear conditions that occur during turbine passage (1220 to 1830 centimeters per second per centimeter) (Moursund et al., 2003, 2006.) In 2011, Pacific Northwest National Laboratory (PNNL) conducted some additional barotraumas experiments using juvenile brook and Pacific lamprey. Juvenile lamprey acclimated to 146.2 kPa (equivalent to a depth of 4.6 m) were subjected to rapid (<1 s) or sustained decompression (17 min) to a very low pressure (13.8 kPa) using a protocol previously applied to juvenile salmon. No mortality or evidence of barotraumas was observed following rapid decompression, nor up to 120 h after sustained decompression (Colotelo et al., 2012). Spillways are assumed to be a relatively benign passage route, though an unknown proportion of juvenile lamprey pass FCRPS dams via this route.

IMPLEMENTATION CONSIDERATIONS

As with adult Pacific lamprey passage improvement implementation, USACE must ensure that alterations of structures and operations at dams do not negatively impact ESA-listed salmon and steelhead. Changes to existing structures or operations must go through established ESA consultation forums (Fish Facility Design Review Work Group, Fish Passage Operations and Maintenance Work Group, etc). Changes must benefit lamprey while having a neutral or positive effect on salmon and steelhead passage.

Prioritization schedules will be determined and potentially modified over the years in consultation with Accord Treaty Tribes, CRITFC, and other regional representatives, and will be dependent on funding availability, technological capabilities, and other considerations.

Juvenile lamprey acoustic transmitter development, tagging studies (passive or active tags), and other research activities will require collection of adequate numbers of Pacific lamprey macrophthalmia and/or ammocoetes to meet study objectives. Historically, most juvenile lamprey used in USACE-funded studies have been collected at dams equipped with juvenile bypass facilities, such as McNary and John Day dams. Given the large sample sizes often required for juvenile fish passage studies at mainstem dams, USACE, Tribes, and other agency representatives must weigh the value of the information gained from the various studies against any potential impacts on Pacific lamprey in the Basin. As such, USACE will continue to coordinate research activities with appropriate tribal staff and resource agencies as studies move forward. In addition to quarterly technical-level planning meetings between USACE and tribal staff, the Anadromous Fish Evaluation Program (AFEP) Studies Review Work Group (SRWG) is an appropriate venue for discussing sample sizes and research impacts on lamprey populations with federal, state, and tribal resource managers.

Below, we provide an accounting of progress on each MOA item, along with proposed actions through 2018.

MOA JL 1: CONTINUE TO MONITOR THE PASSAGE TIMING, NUMBER, AND MORTALITIES OF JUVENILE LAMPREY COLLECTED AT PROJECTS WITH JUVENILE FISH BYPASS FACILITIES.

Juvenile lamprey have been present in the daily samples ever since the juvenile fish facilities (JFF) were opened at each of the Columbia and Snake river dams, with the exception of TDA, which does not have a Juvenile Bypass Systems (JBS) or JFF. The JBS were designed for bypassing salmonids around the dams, but any species of fish that encounters the turbine intake screens can be guided into the JBS. Juvenile Pacific lamprey have been incidentally collected at projects equipped with juvenile bypass facilities, though it is not well understood what proportion of the juvenile lamprey collected in the facilities are relative to the run at large. The Smolt Monitoring Program (SMP) personnel have long enumerated juvenile lamprey, and also separated them into either the "brown" and "silver" categories, with "brown" being the larval life stage, also known as "ammocoete", or "silver" being the out-migrating juvenile life stage, also known as "macropthalmia". There also existed a middle category of "transformers" or fish that were currently morphing from the "brown" to Silver category. Beginning in 2011, SMP personnel began using the more appropriate or more scientific nomenclature of "ammocoete" and "macropthalmia" to make the distinction between the two life stages. Additionally, SMP personnel monitor and record adult Pacific lamprey that periodically fall back through this system.

1. Juvenile Lamprey Collected in Juvenile Bypass Facilities

With the increased emphasis on monitoring of passage timing, numbers, and mortalities of juvenile lamprey under MOA JL1, the projects with bypass systems and fish sampling facilities started making more concerted efforts to find and document the numbers and mortalities in the facilities. Data collected on juvenile lamprey are summarized and available on the Fish Passage Center (FPC) website, under lamprey data, at http://www.fpc.org/lamprey/lamprey_home.html. In a 22 November 2011 FPC memo to the USFWS, FPC stated that they were contacted by the CRBLTWG to make changes to the lamprey collection monitoring at the collection dams. Some of the changes that were requested were: 1) standardized protocols for juvenile lamprey identification (based on USFWS methods), 2) assign a sample rate for juvenile lamprey at the SMP (not treated as an incidental bycatch), 3) develop a condition monitoring program for juvenile lamprey. These revised protocols were implemented beginning in 2011.

2. Monitoring of Juvenile Lamprey Entrainment in Turbine Cooling Water Strainers

The entrainment of juvenile lamprey in turbine cooling water strainers was first identified as a concern in February 2009, when approximately 400 juvenile lamprey mortalities were found in one of the unit strainers at Ice Harbor. Since that time, NWW Operations Division has requested that their mainstem dams conduct monthly cooling water strainer inspections and document the numbers of each fish species found. At a minimum, Lower Granite, Little Goose, Lower Monumental, and Ice Harbor, and McNary Projects have done this. Additionally, Little Goose and Ice Harbor sometimes perform weekly inspections. Juvenile lamprey start showing up in the cooling water strainers in January, and usually coincide with winter precipitation events. In 2012, lamprey were found in the monthly cooling water strainer inspections at each project from January through July, with the peak numbers occurring in March and April. The highest monthly mortality count occurred at Lower Monumental Dam in April, with 770 individuals counted. This number was much lower than the highest count that occurred in 2011 at Lower

Monumental with 1,655 individuals found. It should be noted that occasionally a few live lamprey are recovered and released back to the river.

In 2011, NWW began alternative design development of an exclusion structure to reduce, or eliminate, the number of juvenile lamprey being entrained (although some may be volitional) into the turbine cooling water system. Because the turbine cooling water intake is located in the turbine scroll case, great care needs to be taken to ensure whatever design is chosen, the modification will present a low risk to turbine operation. Because there may be considerable risk associated with installation in the scroll case the alternative design analysis was shifted to the USACE Hydroelectric Design Center (HDC) and is ongoing. The design phase is scheduled to be completed during fiscal year 2014. Ice Harbor Dam has been identified as the most likely candidate for the prototype testing, but the exact location and turbine unit will be selected at a later date.

MOA JL 2: REPLACE WITH SMALLER GAP SCREENS AS WARRANTED WHEN TURBINE INTAKE BAR SCREENS ARE IN NEED OF REPLACEMENT.

The 20% or more of juvenile lamprey that approach powerhouses and encounter turbine intake screens are vulnerable to impingement. Impingement on the screens can result in mortalities under certain conditions as documented by field observations, as well as field and laboratory studies, and that a gap reduction from 1/8 to 2/29 inch virtually eliminated impingement (Moursund 2003, 2006). As a result, USACE has changed screen spacing criteria for new screens to minimize impingement (MOA JL 2) such that as extended screens need replacing the smaller size gap will be used. These screens can last up to 30 years. Accelerating screen replacement is expensive with a cost estimate of around $1M per screen. To better monitor the impingement of juveniles on screens we are exploring if we can routinely enumerate them as they are removed for cleaning and maintenance. As of November 2013, no turbine intake bar screens have been replaced and none are slated for replacement prior to 2018.

MOA JL 3: CONSIDER LIFTING EXTENDED LENGTH SCREENS (PRIMARILY AT MCNARY BUT ALSO AT COLUMBIA AND SNAKE RIVER DAMS) IN CONSULTATION WITH THE NOAA AND THE TRIBES.

Another strategy being considered (MOA JL 3) is to remove screens when juvenile lamprey outmigrate past a project. Unfortunately, there is considerable overlap in the peak of passage with ESA listed salmon juvenile species allowing very little opportunity to remove and reinstall screens considering the time it takes to perform these operations. By examining passage timing of juvenile fish passage at MCN, a dam of particular concern regarding juvenile lamprey passage because of the extended screens at the turbine units, it was determined after regional review that installation of the MCN screens could be delayed until mid April to reduce impingement for downstream passing juvenile lamprey. At MCN, the deployment of extended length screens has occurred each spring since 2009. Similar screen installation timing changes may be able to occur at other dams, although no additional locations, with extended length screens, are currently being discussed.

MOA JL 4: DEVELOP PROTOTYPE LAMPREY SEPARATORS.

At times, juvenile bypass fish facilities can collect thousands of juvenile lamprey that may cause screen clogging, lamprey injury and mortality, and lamprey that are in the raceways during barge loading will be moved into the transportation barges. Fish collected at the transportation collector projects can be held in raceways for up to two days awaiting transportation. Lamprey held in the raceways can become impinged on the tail screens, complicate removing salmon from the raceways, and feed on the salmon. In 2008, USACE began investigations of modifying the tail screens to allow juvenile lamprey to volitionally pass out of the raceways and return to the river without increasing the likelihood of impingement of juvenile salmon on the tail screens.

In 2008 experiments, macrophthalmia were put through a series of screen passage tests conducted in a flume supplied with ambient Columbia River water at the McNary Juvenile Bypass Facility. For each 1 h experiment, five replicates using 10 lamprey each were done with two different screen materials: 6.5 mm square stainless steel woven mesh and stainless steel plate with staggered 6 × 25-mm oval perforations. For each material, we tested the screen in horizontal, angled (9°), and vertical orientations. We found that the macrophthalmia moved most readily through materials oriented vertically (both the mesh and the plate) and were reluctant to move through an angled or horizontal separator. We conducted longer (24 h) experiments using both macrophthalmia and ammocoetes to determine whether fish would volitionally move either vertically, or horizontally through a variety of materials (6.5 mm – 12 mm openings). The results of this work confirmed that macrophthalmia were resistant to moving downward, while ammocoetes readily moved in a downward direction. Both groups moved horizontally through all materials. Based on the findings from the 2008 experiments, a lamprey-friendly raceway screen was built and installed in one of the holding raceways at the McNary juvenile bypass facility. The new screen was oriented vertically and made from 6.5 mm square stainless steel woven mesh (9 mm on diagonal) (Figure 20). Preliminary sampling of raceways with and without the lamprey-friendly screen indicated that fewer juvenile lamprey were retained or impinged by the lamprey-friendly material.

Based on the findings of Moser et al. (2010), all of the projects configured for juvenile salmonid collection and transportation changed the holding raceway screens to the larger spacing (6.5 mm) in 2011 and 2012, to allow juvenile lamprey to volitionally pass from the raceway back to the river through the waste water outfall. Additionally, where needed, the waste water outfall pipes were extended out over the river to areas that had higher velocities to reduce predation.

Figure 20. Screening developed for juvenile lamprey separation, (shown in 2009 test at MCN) in dam bypass systems. The screen on the left is the new 6.5 mm spacing that has been adopted at all of the facilities with transport raceways.

MOA JL 5: WORK ACTIVELY WITH INDUSTRY TO FURTHER MINIATURIZE ACTIVE TAGS THEN DETERMINE PASSAGE ROUTES, OUT MIGRANT TIMING AND SURVIVAL OF LAMPREY THROUGH FCRPS MAINSTEM DAMS.

Little is known about the basic biology of juvenile Pacific lamprey, including juvenile migration. There is a need for methods to study juveniles in mainstem habitats and their migration; to better understand the abundance of juvenile out-migrants and how successful they are at passing through dams. Historically, this type of data has been obtained for salmonids using active telemetry studies, first, with radio tags and recently with acoustic tags.

At present, no active tag is available for use in juvenile Pacific lamprey due to their very small size and girth. Active tags are essential to clearly evaluate and understand basic downstream dam passage parameter such as route specific passage and survival. A tag development program was funded as part of the juvenile salmon FCRPS research program, and an injectable Juvenile Salmon Acoustic Telemetry System (JSATS) tag is now available for use in juvenile salmonid passage studies. Currently, USACE intends to continue this effort as part of the lamprey passage program, with the goal of altering the shape, size, and performance of the JSATS tag to work for future juvenile lamprey passage studies.

Considering the (a) timeline and expense of juvenile lamprey acoustic tag development, and (b) the relatively high cost of acoustic telemetry studies, USACE recognizes the need to carefully assess the value of lamprey-specific tag development relative to management objectives. Constraints regarding further modification of dam configurations and operations designed to protect ESA-listed salmonids should be considered in regional deliberations on this subject. Other approaches may be used to address particular passage routes or issues.

1. Juvenile Lamprey Tag Size and Shape

An initial step in development of a juvenile lamprey tag or implementation of any active *or* passive (i.e. PIT) tag studies is determining an appropriate size or shape for insertion into the body cavity of Pacific lamprey macrophthalmia. In 2009-2010, researchers conducted a study of the biological criteria for an active transmitter that would work with juvenile lamprey migrants (Peery and Loge 2012). A combination of dissections and plastic casts of internal body cavities were used to determine size and shape of available space. Dummy transmitters of various sizes and weights were fashioned and surgically inserted into macrophthalmia. Some lampreys were tagged with PIT tags and some with sham tags to provide a point of reference. Researchers concluded that tag width and volume displacement are critical dimensions. Researchers also observed that an oval cross-section appeared more conducive than round tags for internal anatomy of macrophthalmia. For juvenile lamprey that averaged 159 mm length and 5.2g weight, tags of 15 mm length, 2 to 2.25 mm width and up to 0.35 g appeared feasible. However, fish used for tests were larger than for all fish present in the run at large (averaged 140 mm long, 4.4 g). This must be considered when tag criteria are applied in development of acoustic transmitters and in future field investigations.

2. Juvenile Lamprey Handling and Tagging Protocols

Development of effective tagging and handling protocols is an important step in preparations for future juvenile lamprey tagging studies. In 2012, USACE-funded researchers completed development of a method for tagging juvenile lampreys with passive integrated transponder (PIT) tags (Christiansen et al. 2012). This work generally showed that tagging generally didn't negatively affect tagged macrophthalmia. However, the study also demonstrated that fungal infections were a common problem for captive (control and treatment) juvenile lamprey. In their final report, Christiansen et al. (2012) recommended use of 100 mg/L MS-222 or 60 mg/L BENZOAK® (benzocaine), and a 20-24 hour recovery period followed by immediate release. They also suggested further study to determine whether changes in anesthetics or post-handling treatments (such as holding in salt water) could reduce incidence of fungal infections.

3. Juvenile Lamprey Acoustic Tag Development

With the recent completion of efforts to develop a miniaturized acoustic tag for juvenile salmonid passage studies, juvenile lamprey acoustic tag development will begin in early 2014. Including identification of application space through prototype field testing, the entire design process is expected to take 2 to 3 years and a commitment of up to $2.5 million to complete. Pending funding availability, prioritization, and no major technical challenges, an acoustic transmitter suitable for juvenile lamprey downstream passage studies is expected to be available for production by 2017.

4. Alternative and Complementary Juvenile Lamprey Passage Studies

At a series of juvenile lamprey passage research workshops hosted by USACE between November 2011 and February 2012, participants (including resource managers and lamprey researchers from across the basin) identified the following as the top three general priorities for future juvenile lamprey passage studies:

1. *Determine spatial distribution (vertical and horizontal) of juvenile Pacific lamprey in the forebays of mainstem Columbia and Snake River dams*

2. *Systematic investigation of Juvenile Bypass Systems impacts on juvenile Pacific lamprey*

3. *Determine timing and magnitude of Pacific lamprey macrophthalmia outmigration at mainstem Columbia and Snake River dams*

Participants also agreed that USACE should explore potential means of field capture and recapture techniques to gain additional information about passage and survival of juvenile lamprey through specific passage routes (e.g. turbines, juvenile bypass systems, and spillways) at USACE dams along the lower Columbia and Snake rivers. Feasible alternative approaches must have adequate capture efficiencies and detection probabilities, and minimize potential negative effects on listed juvenile salmonids. Techniques using PIT tags, fyke nets, and towed arrays have been discussed.

During 2013, a study was conducted, at LGR, to assess the biological and debris passage characteristics associated with the current gatewell orifice size (10 inch) and two new configurations for passage from the gatewell to the collection channel (an enlarged 14-inch orifice and a broad-crested overflow weir). Specifically, the objectives were: 1) determine how the overflow weir and/or larger orifices affected orifice passage efficiency and travel times through the JBS compared to current orifice configuration for juvenile salmonids and lamprey, 2) determine fish condition (including injury and descaling) impacts of the overflow weir and/or larger orifices compared to current orifice configuration for juvenile salmonids, 3) determine debris passage impacts of the overflow weir and/or larger orifices, and investigate salmonid fish behavior patterns in gatewells with the overflow weir relative to current orifice configuration (O'Connor et al. in prep). Additional objectives specific to juvenile lamprey were: 1) determine effective collection methods for juvenile lamprey at LGR, Little Goose (LGS), and Lower Monumental (LMN) dams, 2) determine collection efficiency for juvenile lamprey designated for recollection at the Sort by Code (SbyC) system at LGR, 3) evaluate PIT tag retention using two different tagging techniques: surgical methods described by Mesa et al. (2011) and injecting smaller 8.5 mm PIT tags with a 16-gauge needle.

Juvenile lamprey were included in this evaluation, as a pilot effort, because no large scale collection effort has, to our knowledge, ever taken place and it was unknown whether the proposed sample size of 1 to 2 thousand was obtainable. Juvenile lamprey were collected at SMP facilities at LGR, Little Goose (LGS), and LMN dams. A tag retention comparison was conducted with 75 fish tagged with scalpels and 75 tagged by injecting a 8.5 mm L x 1.4 mm Dia PIT with a 16 gauge needle (a new technique not quantified in the literature). Each group was held for 96 h then inspected for tag sheds and healing of surgical wounds. No mortalities occurred during the holding period. The group tagged with scalpels had 2 shed tags and 66.7% had unhealed tag wounds. The group injected with 8.5 mm PIT tags had no shed tags and 5.7% had unhealed tag wounds.

Overall Passage Efficiency from the gatewell to the JFF for lamprey ranged from 95.7%-99.0% depending on release location, indicating that the JBS at LGR is effective for these species. Juvenile lamprey were released at night and had the lowest travel times when released during operation of the broadcrested weir (0.3 h). However, there was no statistical difference in passage times between the weir and the enlarged orifice indication that either prototype structure passed juvenile lamprey more quickly than traditional 10” orifices.

This pilot study answered some feasibility questions about collection, handling, tagging, releasing, and recollecting (via Sort by Code) juvenile lamprey for JBS passage evaluations. It provided some insights and data on orifice passage efficiency within the gatewells, travel times from the gatewells to the JFF, as well as some travel time and detection efficiency information to some downstream projects. It also allowed us to start answering questions relative to an identified goal from the juvenile lamprey workshops, namely the need for systematic investigation of JBS impacts on juvenile Pacific lamprey. Juvenile lamprey were collected at the three projects from May 15 through May 31, 2013, so this short sampling period was not long enough to provide much information on the outmigration timing and magnitude question posed by juvenile workshop participants.

MOA OP 1 (ADAPTIVE MANAGEMENT): LARVAL LAMPREY REARING IN THE MAINSTEM COLUMBIA AND SNAKE RIVERS

Pacific lamprey have a complex life history that includes a three to seven year larval (i.e., ammocoete), migratory juvenile (i.e., macropthalmia) and adult phases. Ammocoetes and macropthalmia are strongly associated with stream and river sediments. Ammocoetes live burrowed in stream and river sediments for periods up to seven years after hatching, where they filter feed on detritus and organic material. Ammocoetes metamorphose into macropthalmia from July to December and migrate downstream to the Pacific Ocean. The timing, duration, and habitat use of the larval life stages are poorly understood. For Pacific lamprey, the majority of the information on habitat preference of larvae comes from Columbia River Basin tributary systems. Lamprey larvae are known to occur in shallow stream sediments but their use of comparatively large river habitats in relatively deeper areas is poorly understood, but recent studies indicate that Pacific lamprey ammocoetes occupy mainstem areas of the Columbia and Willamette rivers, including reservoirs created by hydropower facilities.

Obtaining information concerning if and how ammocoetes use the areas above and below dams is critical to understanding the importance of these areas for long term population viability. At present, little specific information is available on how many larvae use these areas, when and how long they use these areas, whether they tend to be found in specific locations, and the effects of hydrosystem operations on larval lamprey.

The U.S. Fish and Wildlife Service has been exploring occupancy, detection, and habitat use of ammocoetes in relatively large, mainstem river habitats, including the Willamette and Columbia rivers (Figure 21). In a USACE-funded USFWS study initiated in 2013, Pacific lamprey ammocoetes were found to occupy the reservoirs above Bonneville and The Dalles, including the mouths of the Wind, White Salmon, Hood, Klickitat, and Deschutes rivers (J. Jolley, personal communication). A broad range of sizes were present suggesting multiple ages and long-term rearing. In 2014, USFWS field surveys will continue upriver as researchers from the PNNL use bathymetric data, field surveys, and other data to map mainstem ammocoete rearing areas that are most susceptible to dewatering. Concurrently, researchers from USGS will conduct a laboratory study to evaluate ammocoete response (behavior, condition, and survival) to dewatering simulations.

Figure 21. Photos of USFWS personnel using deepwater electrofishing gear to assess Pacific lamprey ammocoete occupancy in the Columbia River. Electrical current is used to temporarily stun the lamprey, which are quickly pumped to the surface for species verification (Pacific vs. western brook lamprey) and measurement. Photos courtesy of USFWS.

CONCLUSION

The purpose of this update to the 10 Year Plan is to assess lessons learned since 2008 and, based on that information, provide a revised and more detailed path forward through 2018. Implementation of this plan is dependent upon the availability of funds. Working in collaboration with Treaty Tribes, States, and other federal agencies, USACE will continue to use an adaptive management approach as we continue implementation of lamprey passage improvements and studies. We will continue to provide annual progress reports documenting actions and will, consistent with the Pacific Lamprey Conservation Agreement, coordinate with regional partners as part of a regional effort to reverse population declines of Pacific lamprey in the Columbia River Basin.

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