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Pacific Lamprey 2011 Annual Report and 2012 Plan

Columbia/Snake River Salmon Recovery Office
Pacific Northwest Region

U.S. Department of the Interior
Bureau of Reclamation

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Pacific Lamprey 2011 Annual Report and 2012 Plan

Prepared to document and communicate Reclamation's actions pertaining to Pacific Lamprey under the commitments in the 2008 Columbia River Fish Accords.

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Introduction

Bonneville Power Administration, U.S. Army Corps of Engineers, and the Bureau of Reclamation (Reclamation) (collectively known as the Action Agencies) operate the Federal Columbia River Power System (FCRPS). In 2008 the Action Agencies entered into a Memorandum of Agreement with several Columbia River Basin states and Tribes, known as the 2008 Columbia River Basin Fish Accords (Accords). The Accords include agreements to implement and fund numerous fisheries and habitat-related actions to improve fish survival in addition to those already prescribed in the RPA in the 2008 NOAA Fisheries Biological Opinion on the FCRPS (NOAA Fisheries 2008). Several actions in the Accords dealt specifically with Pacific lamprey.

In the Fish Accords, the action agencies each agreed to pursue or implement actions to address and potentially reverse the recent decline in Pacific lamprey numbers in the basin. Reclamation's commitments are as follows:

1. Beginning in 2008, and concluding in 2010, Reclamation will conduct a study, in consultation with the Tribes, to identify all Reclamation projects in the Columbia River Basin that may affect lamprey. The study will also investigate potential effects of Reclamation facilities on adult and juvenile lamprey, and where appropriate, make recommendations for either further study or for actions that may be taken to reduce effects on lamprey. The priority focus of the study will be the Umatilla and Yakima projects and related facilities.
2. Beginning in 2008, Reclamation and the Tribes will jointly develop a lamprey implementation plan for Reclamation projects as informed by the study above, the tribal draft restoration plan, and other available information. The plan will include priority actions and identification of authority and funding issues. It will be updated annually based on the most recent information. Reclamation will seek to implement recommended actions from the implementation plan (2008 River Basin Fish Accords, Memorandum of Agreement between the Three Treaty Tribes and FCRPS Action Agencies, May 2008).

The purpose of this report is to document and communicate Reclamation's actions under these commitments on an annual basis. This first annual report will focus on activities conducted in 2011 and will include updates on activities to date since the signing of the Accords in 2008. This report also communicates the final Assessment of U.S. Bureau of Reclamation Projects in the Columbia River Basin: Effects on Pacific Lamprey (*Lampetra tridentata)* and Reclamation's Pacific Lamprey Plan.

Partners

Reclamation lead office for Pacific lamprey activities is Pacific Northwest Regional Office (Reclamation PNRO). Other Reclamation offices include:
Reclamation Columbia Cascades Area Office (Reclamation CCAO)
Reclamation Yakima Field Office (Reclamation YFO)
Reclamation Umatilla Field Office (Reclamation UFO)
Reclamation Technical Services Center (TSC)

Reclamation partners with a variety of agencies and organizations for Pacific lamprey activities, including:
Columbia River Intertribal Fish Commission (CRITFC)
Yakama Nation (YN)
Confederated Tribes of the Umatilla Indian Reservation (CTUIR)
U.S. Fish and Wildlife Service (USFWS)
National Oceanic and Atmospheric Administration, Fisheries (NOAA Fisheries)
U.S. Geological Survey (USGS)
U.S. Army Corps of Engineers (USACE)
Lamprey Technical Working Group (LTWG)

2011 Collaboration Activities

Reclamation staff and managers attended a variety of meetings, conferences, workshops, and other functions in 2011 to support Pacific lamprey activities in a cooperative and collaborative manner. These are listed below:

- **Columbia River Intertribal Fish Commission (CRITFC) –**
    - Staff attended meeting of CRITFC biologists in Hood River, OR (January).
    - PN Regional Director and Deputy Regional Director met with the Commission meeting (January)
    - Regional Director hosted CRITFC Executive Director and staff in Boise (August)
    - Deputy Commissioner and staff met with CRITFC staff in Washington D.C. (October)
- **Yakama Nation Cooperative Agreement –** Staff worked with YN to develop Scope of Work and administrative requirements to implement Cooperative Agreement R11AC17069, a 4-year, $420,000 agreement for lamprey work in the Yakima Basin.
- **CTUIR Coordination –** Staff worked with CTUIR to develop draft Scope of Work and collaboratively defined other mechanisms to implement lamprey entrainment studies in the Umatilla Basin.
- **Yakama Nation Draft Tribal Lamprey Restoration Plan –** Staff attended work sessions (January/February), provided input, then reviewed and provided comment on draft Plan.

- **First International Symposium on the Recovery and Propogation of Lamprey –** Staff participated in symposium sponsored by CRITFC and Yakama Nation (April).
- **Accords Celebration** event in The Dalles, OR (May) – PN Regional Director presented and managers/staff attended the event.
- **Yakima Basin Joint Board of Control –** Staff presented with Bob Rose (Yakama Nation) on lamprey issues and activities in the Yakima Basin to a meeting of the Joint Board (July).
- **Washington State Water Resources Association -** Staff presented with Bob Rose on lamprey issues and activities at annual meeting in Spokane, WA (December)
- **Corps of Engineers Juvenile Lamprey Workshop –** Staff attended juvenile lamprey workshop (August) for information-sharing on current research and juvenile lamprey monitoring capabilities/techniques.
- **Corps of Engineers Anadromous Fish Evaluation Program** – Staff attended lamprey portion of the annual review in Walla Walla, Washington (December).
- **Lamprey Technical Working Group –** Staff attended and participated in workgroup meetings (May and December).

Assessment of Reclamation Projects

Background

This Assessment, titled "Assessment of U.S. Bureau of Reclamation Projects in the Columbia River Basin: Effects on Pacific Lamprey (*Lampetra tridentata*)" documents the activities undertaken to satisfy the Fish Accords commitment to identify Reclamation projects that may affect Pacific lamprey, investigate potential effects, and make recommendations for further study or actions. The report was prepared following numerous site visits and meetings with Reclamation staff, contractors, YN, CTUIR, CRITFC, and others from 2008-2010. The Draft Assessment was released to CRITFC and the Tribes in December 2010. Comments were received from YN and CTUIR, with informal communication from CRITFC indicating they deferred comments to the individual Tribes. The Draft Assessment was subsequently presented to the Yakima Basin Joint Board of Control (representing Yakima Basin irrigation districts), and provided to them for comment. Comments were received from the districts' contractor, D.C. Consulting (David Childs) and Fish Passage Solutions (John McKern) in December 2011. Additionally, the Draft Assessment and other lamprey activities were presented to a larger irrigator audience at the Washington State Water Resources Association Annual Meeting in Spokane in December, 2011. Comments from all parties were incorporated throughout 2011, resulting in a Final Assessment.

Assessment Summary

The full Assessment is attached as Appendix A, and a summary is presented here.

Introductory Chapters

The introduction chapter describes the background and introductory information leading to development of the Assessment. The second chapter describes the approach taken to investigate potential effects of Reclamation projects included attendance at a number of Tribal and federal workshops; meetings with Tribal, state, and federal biologists; site visits to projects, and examination of existing lamprey information. All Reclamation and some non-Reclamation facilities were visited and evaluated to gain understanding of the “big picture” basin-wide and better understand Reclamation facility effects. The third chapter discusses the historical and current status of Pacific lamprey in the Columbia River Basin, including focused discussion on status in the Yakima and Umatilla River Basins.

Chapter four sets the groundwork for evaluating Reclamation project effects with a discussion of issues affecting lamprey in general and opportunities such as ongoing work to address those issues. Disruption of migratory corridors, both upstream adult and downstream juvenile migrations, is listed as a documented threat and reason for decline of Pacific lamprey. Factors or conditions that might limit or impede adult Pacific lamprey upstream passage include dam configuration, seasonal changes in flow, water temperature, predation by birds and other predators, or the amount of debris above, below, and on the dams. Factors or conditions that might limit or impede juvenile lamprey downstream passage include seasonal changes in flow, water temperature, possible avian predation, predation by other fish species, the large amount of debris above, below, and on the dams, possible entrainment into irrigation canals, configuration and operation of the juvenile fish bypass systems if fish are diverted into the canals, etc. There are numerous opportunities to address issues as many agencies are working on lamprey. Adult Passage Structures (LPS) are relatively simple structures being designed and implemented to facilitate lamprey passage on the mainstem Columbia River dams and in some tributary diversion dams. Studies are also in progress to learn more about juvenile entrainment protection requirements.

Assessment Chapters

Yakima River Basin

The remaining chapters are the assessments of individual project areas with Chapter five evaluating the Yakima River Basin Projects. Reclamation diversion dams in this chapter include Prosser, Sunnyside, Roza, Easton, Wapatox, and Yakima-Tieton.   Non-Reclamation diversions examined include Horn Rapids, Wapato, Town, Naches-Cowiche, Gleed, Naches-Selah. Some of these non-Reclamation projects have Reclamation ties through operation and maintenance agreements of fish structures. Possible effect mechanisms of these diversions were primarily adult passage issues and possible entrainment of juveniles into canals and/or harm of individuals by screening mechanisms. Each facility is described to determine specific issues and recommendations for adult passage and juvenile protection.

Figure 1 – Prosser Diversion Dam on the Yakima River

Reclamation storage facilities high in the upper Yakima basin are Keechelus, Kachess, Cle Elum, Tieton, Clear Creek, and Bumping Lake. Due the location so high in the basin, it is unknown if these areas were historically occupied by lamprey. These facilities may affect lamprey habitat downstream due to interruption of sediment transport and operational effects on water temperatures. It was determined that at this time it is more appropriate to focus restoration efforts on adult and juvenile issues at lower Yakima River locations. If Pacific lamprey restoration efforts successfully re-establish populations that may use these upper basin habitats, it would be useful to reanalyze these upper basin project effects and opportunities.

Yakima River Basin recommendations are influenced by the low populations of Pacific lamprey in the basin, which focuses on getting adults into the basin as a priority. Recommendations for the Yakima River Basin are:

- Gather information, via support of the FWS radiotelemetry study and other data collection to determine passage routes and site specific data needed to plan adult passage.
- Populations are very low and there may be a need to supplement the study with individuals from the Columbia River. This may require overwintering capability; opportunity for this at Reclamation facilities should be explored.
- Support and assist Yakama Nation’s translocation and propogation efforts through facilities where opportunity exists, and funding support.
- Consider adult lamprey passage structures where feasible and where data indicates the need, with focus in the lower river. Use results from radiotelemetry study to prioritize and design structures.

- Conduct surveys behind fish screens at Reclamation projects, and use data to prioritize locations for further study to quantify entrainment or effect on juveniles and determine mechanisms of effects.
- Support ongoing work to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey where determined appropriate.

Umatilla River Basin

Umatilla River Basin facilities evaluated in Chapter six include Reclamation's Three Mile Falls Diversion Dam, Maxwell Diversion Dam, Feed Canal Diversion Dam, and McKay storage reservoir. Non-Reclamation facilities include Dillon, Westland, and Stanfield Diversion Dams. There is also a diversion for the privately-owned Boyd Hydroelectric facility that is currently breached. Effects from these facilities are primarily passage and entrainment issues at diversions. Each facility is described to evaluate individual levels and mechanisms of possible effects. In this basin there has been some progress for adult passage through structural modifications. An LPS was installed at Three Mile Falls Diversion in 2009, and at Feed Canal Diversion Dam in 2010. Maxwell Diversion Dam has a steel plate added to the middle of the diversion to facilitate adult lamprey passage.

Figure 2 - Three Mile Falls Diversion Dam on the Umatilla River

The Umatilla River Basin has successful translocation populations and some progress in adult passage capability. The priority in this basin is on juvenile protection issues and monitoring adults movements as needed. Recommendations include:

- Monitor effectiveness of adult lamprey passage at Reclamation facilities
- Study migration and timing of juveniles in system
- Continue and expand surveys behind fish screens at Reclamation projects, and use data to prioritize locations for further study to quantify entrainment or effect on juveniles and determine mechanisms of effects.
- Support ongoing work to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey.

Other Basin Projects

While the focus for this assessment and recommendations for further efforts is Reclamation' projects in the Yakima and Umatilla River, there are other

Reclamation projects in the Columbia basin that may also affect Pacific lamprey. These projects, in the Deschutes, Tualatin, and Snake River Basins, are described in this chapter with some preliminary observations of any associated lamprey issues. There are no recommendations at this time associated with these projects.

Deschutes River Basin - All Reclamation facilities are in areas where Pacific lamprey are currently excluded by downstream barriers. Reclamation facilities are described to provide information to evaluate possible effects to lamprey if restoration efforts were to result in presence of lamprey.

Tualatin River Basin - Reclamation facilities are in areas far upstream of known Pacific lamprey populations and are in marginal lamprey habitat. Facilities are described to provide information to evaluate possible effects to lamprey if restoration efforts were to result in presence of lamprey.

Snake River Basin -The only Reclamation project in the Snake Basin downstream of Hells Canyon complex (uppermost limit of Pacific lamprey), is the Lewiston Orchards project. No direct effects to lamprey passage or entrainment are noted for this project. Project descriptions are provided but not assessed in detail for lamprey effects.

Summary

This report serves to document Reclamation's assessment of projects in the Columbia River Basin that may affect Pacific lamprey, with a focus on the Yakima and Umatilla basins. Reclamation is committed to coordinating and collaborating with the Tribes and other partners to further assess the issues of effects on Pacific lamprey in the Columbia River basins, further the knowledge of Reclamation project's effects on Pacific lamprey, and explore options to implement passage, protection measures, and/or other activities as informed by these studies.

Lamprey Activity Summaries

Reclamation has been involved in or supported a number of studies and activities since the Accords were signed in 2008. This section provides a brief summary of each of these activities. In many cases Reclamation is one of several partners collaborating on a study or activity. For each study, the "Background" section outlines the needs and objectives for the study and the extent of Reclamation involvement. The "Update" is either an abstract, executive summary, or narrative summary of the work to date with an emphasis on work in 2011. If a report has been submitted by the study lead, that report is attached as an appendix and the abstract or executive summary is used for the "Study Update" section. Finally, the "Future Plan" is a brief narrative describing Reclamation's plan relative to that particular study or activity.

Umatilla Basin Passage Structures

Background

CTUIR has been actively working to restore Pacific lamprey populations to the Umatilla River basin through translocation, and led the effort to enhance passage throughout the Umatilla basin for adult lamprey. Reclamation involvement includes funding and technical support to provide passage at Reclamation structures. NOAA Fisheries has also provided technical expertise and support.

Update

Adult lamprey passage structures have been installed on all three of Reclamation's diversions in the Umatilla basin. CTUIR and NOAA Fisheries collaborated to install a Lamprey Passage System (LPS) at Three Mile Falls Diversion in 2009. A flat plate was added to Maxwell Diversion Dam in 2010 to enhance passage for Pacific lamprey. An LPS was installed at Three Mile Falls Dam in 2010. Monitoring the operation and maintenance of this LPS indicates a need for minor modification to protect the structure from debris.

Figure 3 – Lamprey Passage System on Feed Diversion Dam

Future Plan

Reclamation is developing a plan with CTUIR and other partners to monitor and evaluate of the efficacy of these structures in relation to adult Pacific lamprey movements in the Umatilla River Basin. Reclamation also plans to make minor modification to the handrail of the Feed Diversion Dam LPS to protect the structure.

Umatilla Projects Juvenile Lamprey Sampling

Study Lead – Reclamation Technical Service Center

Zachary Sutphin
Fish Biologist
Fisheries and Wildlife Resources Group
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Background

Reclamation worked with CTUIR to begin implementing recommendations from the Assessment document. One of these recommendations was to systematically sample Reclamation canals shortly after water delivery shutdowns to estimate the effect of juvenile lamprey being entrained through fish screens and being left stranded in canals. The primary objective was to complete short-term data collection efforts to estimate entrainment loss at Feed, Maxwell, and West Extension Canals, shortly after dewatering. Reclamation's TSC and PNRO staff worked with CTUIR to implement this study, with CTUIR providing equipment and training. Reclamation is the lead on this study.

Update

The 2011 Annual Report is attached as Appendix B, with a summary provided here.

Presence of Early Life-Stages of Pacific Lamprey Above and Below Water Intake Screens in Bureau of Reclamation Canals in the Umatilla River Basin

Zachary Sutphin, Eric Best, Susan Camp

Canals were sampled using backpack electrofishers to assess Pacific lamprey presence/absence up- and downstream of Reclamation canal screening facilities. CTUIR provided the equipment for sampling, assisted with sampling at Feed Canal, and trained Reclamation staff how to use the specialized equipment and protocols for effective lamprey sampling. Electrofishing methods were followed to be consistent with those used for juvenile lamprey sampling by CTUIR throughout the basin. Within each location multiple sites were selected based upon the best available habitat most likely to support lamprey both above and below screen facilities. Sampling focused on efforts to systematically cover as much habitat as possible to detect lamprey presence as well as to perform salvage efforts if lamprey were found.

Figure 4 – Reclamation and CTUIR sampling Feed Canal for juvenile lamprey.

Feed Canal was sampled on April 27 and 28, 2011, following dewatering of the canal on April 20, 2011. The entire length of the canal was evaluated and suitable sampling sites were determined. Twelve sites were sampled, with the first site covering the entire area between the diversion and the fish screen structure, and the remainder spread out over the rest of the canal downstream of the screens. Electrofishing conditions and visibility were generally good, and habitat (water and sediment) appeared suitable for lamprey to survive if stranded in the canals. Total sampling time was 854 minutes (222 minutes upstream of the screens, 374 minutes downstream) electrofishing 2,332 m^2 of wetted area suitable habitat (1700 m^2 upstream of the screens, 632 m^2 downstream). Note: Sampling pace above the screens was done according to 7.5 m plots in 11 minutes protocol for study plots, then additional area was covered more quickly in a salvage effort. Across all efforts in Feed Canal, only one lamprey ammocoete was seen. It was originally spotted swimming away from just upstream of the fish screen structure and was targeted and captured on the next sampling plot. No lamprey were observed or captured in the canal downstream from the fish screens.

Maxwell Canal was sampled on October 18 and 19, 2011 following dewatering of the canal on October 14, 2011. The distance from the diversion to the fish screen and bypass at Maxwell is about 2.44 km. Twelve sample sites were electrofished using the study protocol pace in this section, then two additional plots of 44 m^2 each were sampled over a period of 32 minutes each in an effort to cover more area to detect/salvage lamprey. In addition, the concrete apron immediately upstream of the screens was recently dewatered and covered in sediment. A pitchfork was used to work through about 15 m^2 of this sediment in an attempt to detect stranded lamprey. Downstream of the screens, twelve sample locations were electrofished, again targeting likely lamprey habitat, spaced out from the screen structure to the end of the canal. A total of 575 m^2 (290 m^2 upstream of the screens and 285 m^2 downstream of the screens) was sampled over 592 minutes (328 minutes upstream, 264 minutes downstream). No lamprey were detected at any of the sampling sites in Maxwell canal.

West Extension Canal was sampled November 2 and 3, 2011 following dewatering of the canal on November 1, 2011. All areas containing exposed or submersed soft sediment above the fish screen to the headworks on West Extension Canal, as well as below the screens to the stop-log channel in the post-screen bay, were sampled. Sampling in areas immediately up- and downstream of the fish screens constituted electrofishing all locations containing submersed soft sediment habitat, as well as walking and visually inspecting the entire area for stranded lamprey, and working though soft sediment with a pitchfork. The entire length of West Extension Canal, from the stop-log channel below the fish screens to the end of the canal is concrete lined, so sampling efforts focused on areas containing soft sediment, which was generally at concrete check structures. The entire area upstream of screens in the forebay area, 124 m^2 was sampled in a little over 31 minutes of electrofishing in addition to visual inspection of stranded lamprey. Most of the bay downstream of the screens was sampled with five independent pools of water sampled in 35 minutes of electrofishing. Additionally, upon returning to the headworks area the following day, the drum screens had been raised for maintenance so the area under and inside the drum screens was visually inspected, with one lamprey being found inside a screen. Downstream from the post-screen bay, the canal was sampled at 3 additional locations (soft sediment deposits at check structures and at canal end) comprised of 19 sample sites resulting in 285 m^2 of area sampled over 209 minutes. Thirteen lamprey were collected through either visual salvage or electrofishing the area between the diversion and the fish screens. One was found inside the drum screen after it was raised. No lamprey were detected downstream of the fish screens either in the bay or on downstream in the canal.

Future Plan

Systematic sampling in 2011 of all three Reclamation canals on the Umatilla River yielded very few lamprey overall, and no lamprey were found beyond the screen structures at any of the facilities. Further work may be warranted to better understand the interactions of lamprey larvae and juveniles with project structures. This first year of sampling seems to have unusually low numbers of lamprey ammocoetes and macropthalmia observed around these structures. This water year was characterized by an extremely cool spring resulting in later than normal runoff and unusually high flow events prior to sampling that may have altered "typical" behavior and migration patterns of lamprey.

Reclamation plans to continue this effort of sampling for stranded lamprey in canals of the Umatilla projects in 2012 and 2013. Additionally, other sampling methods and experiments are being explored to provide a more complete picture by allowing for the quantification of lamprey actively entrained into diversions and past screening structures. For example, a mark-recapture experiment, using individually marked (e.g., PIT tags) or batch marked (e.g., coded wire tags, visible implant elastomer tags) ammocoete lamprey released in the mainstem Umatilla River upstream of water diversions in the region, and completing active (i.e., electrofishing, fyke netting) or passive (i.e., fixed PIT tag antenna arrays and or PIT tag backpack units) sampling efforts in canals could be used to determine the proportion of lamprey released in the river subject to entrainment into the canal. This experiment could also help determine the efficiency of screens in the field setting by comparing the disposition of lamprey once they enter the canal system (i.e. bypassed back to river vs. going through screens and on down the canal). Furthermore, rates of juvenile lamprey entrainment could be enumerated by employing a fyke net system customized to sample unmarked drifting ammocoetes in the canal below the screens as well as bypass flows giving us a total number of lamprey that were: 1. Entrained into the canal 2. bypassed back into the river and 3. passed through the drum screens. These types of studies are more intensive than the post dewatering canal sampling and it may not be feasible to do them at every structure or all in one year. Reclamation will work with CTUIR to plan and prioritize future entrainment study efforts.

Yakima Radiotelemetry Study

Study Lead – US Fish and Wildlife Service

RD Nelle
Mid-Columbia River Fishery Resource Office
Leavenworth, WA

Interagency Agreement R10PG10402

Background

Determining the movements of adult Pacific lamprey into and through the Yakima River Basin was determined to be a priority research need. Reclamation is providing funding to USFWS for a cooperative radiotelemetry study in the Yakima Basin. Other contributers to this study include YN, BPA, and USACE. The objectives of this study are to determine adult Pacific lamprey passage at the Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, time in the fishways, total time spent at the dams, and migration rates between dams. In addition, areas where Pacific lamprey over-winter and spawn in the Yakima River will be located if possible. This information will further develop our understanding of how Reclamation diversions (and other diversions) may affect the migration of adult lamprey and provide information for prioritization, conceptualization, and design of possible lamprey passage structures.

Update

The full annual update report, covering Fiscal Year 2011 (Oct 2010-Sept. 2011) is attached as Appendix C, and the abstract is presented here. Additional work completed in Sept.-Dec. 2011 is summarized after the abstract.

Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversions - 2011 Annual Report

Andy Johnson, Mark Nelson, RD Nelle

Abstract- The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River and its tributaries. Numbers of adult lamprey returning to the tributaries have declined in recent years due to several contributing factors including hydroelectric and diversion dam operations, habitat degradation, and pollution. The Yakima River has several diversion dams that may be obstacles in the upstream migration of adult Pacific lamprey. Lamprey are known to pass some of these dams but very little is known about their residence times and passage routes. We used radio telemetry to determine approach timing, residence time, fishway routes, other passage routes, and migration rates at the diversion dams on the Yakima River. Wanawish, Prosser, and Sunnyside dams were equipped with telemetry stations. Stations were also established on Satus and Toppenish creeks and near the mouth of the Yakima River.

Figure 5 – Fixed receiver station installation on Prosser Dam

Eight Pacific lamprey, collected at John Day Dam the previous summer, were radio-tagged and released above and below Wanawish Dam on March 30, 2011. Five lamprey made upstream movements and approached at least one dam. Three lamprey were depredated or scavenged by mammalian predators. Upstream movements were made during periods of decreasing discharge and mostly during night hours. Lamprey made first approaches at the dams

between April 1 and August 2. One lamprey successfully passed through Wanawish Dam. Two were successful in passing Prosser Dam. One lamprey moved up to Sunnyside Dam but did not pass before the transmitter battery died. For lamprey that passed a dam, total residence time ranged from 29.9 to 81.1 days with fishway passage times between 0.15 and 6.33 days. The average migration rate between dams was 11.35 km/day. Our sample size was small but initial results indicate that while the diversion dams on the Yakima River are passable by adult Pacific lamprey, they appear to be impediments to upstream migration. As the study continues, we will adaptively modify the telemetry stations and tag and release greater numbers of lamprey to gather more detailed information on movements at the dams.

Fall 2011 Update - A total of 42 adult Pacific lamprey were tagged at the Yakama Nation's Prosser Hatchery Facility during September 13-15, 2011. On October 4th, after being held for 3 weeks, 41 lamprey (one tag was shed during holding) were released into the Yakima River. Release locations were in close proximity to Wanawish Dam (river kilometer (rkm) 29) and Prosser Dam (rkm 75). Sixteen lamprey were released 0.45 km downstream of Wanawish Dam and five were released 1.2 km upstream of the dam. Sixteen were released 0.30 km downstream of Prosser Dam and four were released 1.1 km upstream. Upstream movements by several individuals were detected the following day with one lamprey successfully passing upstream of Prosser Dam the night of release. Frequent movements, both upstream and downstream, were detected until early November when movements ceased. All lamprey released above the dams made upstream movements while approximately two-thirds of those released below the dams are still in close proximity to their release location. Six lamprey passed upstream of a dam before overwintering; one moving up as far as Wapato Dam (rkm 171.5).

Additional fixed stations were also installed during the fall of 2011. An access issue was resolved between Reclamation and a private landowner which allowed for access to the river right side of Sunnyside Dam (rkm 167) and a fixed station was installed there, thus the dam set up is complete. Wapato Dam was fully set up with three fixed stations. By working in cooperation with the Yakama Nation, a fixed station at the Roza Outfall (rkm 182) is scanning for Pacific lamprey and acting as a "gate" to detect if any lamprey migrate upstream out of the study area. Solar panels were also installed on all the fixed stations at the dams for a back-up power source when the AC power supply is lost.

Future Plan

Reclamation plans to continue funding this study in FY2012 and outyears as determined by the results. The initial year of this study, 2011, had a relatively small sample size and adaptive telemetry tracking design. It was a successful pilot to guide future release and monitoring strategies, and provided some valuable preliminary information regarding lamprey movements in the Yakima Basin.

Yakima Project Canals Juvenile Lamprey Sampling

Study Lead - Yakama Nation
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Pacific Lamprey Project Leader
Goldendale, WA
Cooperative Agreement R11AC17069

Background

Reclamation worked with YN to begin implementing recommendations from the Assessment document. One of these recommendations was to systematically sample Reclamation canals shortly after dewatering to estimate the effect of juvenile lamprey being entrained through fish screens and being left stranded in canals. YN performed a pilot sampling effort in 2011 under cooperative agreement with Reclamation. YN also sampled non-Reclamation canals with separate funding, and had previously done some sampling in 2010. Results of both sampling efforts are presented together in a single report.

Update

The full report is attached as Appendix D. A summary of 2010 and 2011 results is provided here:

Reclamation projects sampled include Prosser, Sunnyside, and Roza Diversions on the Yakima River, and Wapatox Diversion on the Naches River. Non-Reclamation projects surveyed included Horn Rapids, Wapato, Selah/Moxee, and Cowiche. Reclamation has operation and maintenance agreements and/or ownership of fish screen facilities at these non-Reclamation diversions. Surveys were done using standard lamprey electrofishing protocols and took place as canals were dewatered from late October to mid November of both 2010 and 2011, with the exception of Wapatox, which was only sampled in 2011.

In the Yakima River Basin, Western brook lamprey (*Lampetra richardsoni*) are a common, non-anadromous species that is very similar in appearance to Pacific lamprey as ammocoetes. At very small life stages, such as captured in the canals, they are indistinguishable in field identification. Electrofishing surveys captured lamprey at some diversions sampled (Reclamation and non-Reclamation) in 2010 and 2011. Due to the small size of most lamprey captured, field identification was not possible so a subsample was selected from captured lamprey for laboratory identification. None of the lamprey sampled were identified as Pacific lamprey.

The total number of lamprey captured at each diversion in 2010 and 2011 is shown in Table 1, with the numbers captured in front of the screens and behind the screens listed. It should be noted that these numbers are not directly comparable as there was much more habitat available throughout the length of the canal downstream of the screens than what was available in front of the screens, so there was much more effort behind the screens. Suitable habitat for lamprey juveniles was found and targeted at all locations, but in some cases sampling was not conducted in front of screens.

Table 1. Number of lamprey captured at each diversion.

YEAR Diversion	**2010** Front	**n = 2427** Behind	**2011** Front	**n = 832** Behind
YAKIMA				
Horn Rapids	0	0	0	0
Prosser/Chandler	0	0	0	0
Sunnyside	NA	1292	NA	224
Wapato/New Rez.	325	358	83	360
Selah/Moxee	0	0	38	0
Roza	0	24	29	0
NACHES				
Cowiche	201	227	0	0
Wapatox	NA	0	98	0

No Pacific lamprey were found in any of the samples. No lamprey were found at Horn Rapids or Prosser Diversions. At Sunnyside Diversion, only sites behind the screens were sampled; no sampling was conducted in front of the screens. At Wapato, lamprey were found both in front and behind screens. At Selah/Moxee no lamprey were found in 2010 and a few were captured in front of the screens in 2011. Lamprey were captured at Roza behind the screens in 2010 and in front of the screens in 2011. At Cowiche, lamprey were found in 2010 but none were sampled in 2011. Finally, sampling at Wapatox found none in 2010, but some in front of screens only in 2011.

Future Plan

Electrofishing surveys of Reclamation canals found numerous Western Brook or unidentified lamprey both above and behind screens, but none were identified as Pacific lamprey. The presence of Western brook lamprey behind screens indicates the screens may not be an effective barrier to prevent entrainment of lamprey, but their effect on Pacific lamprey is not known. There is little documented reproduction of Pacific lamprey in the Yakima River Basin and therefor likely a low chance of Pacific lamprey juveniles in the river and subject to entrainment. As Pacific lamprey propogation, translocation, and reintroduction efforts progress, there are likely to be more of this species' juveniles in the river. Reclamation plans to continue funding YN in Fiscal Year 2012 to do electrofishing surveys of canals as they are dewatered to determine the presence/absence of Pacific lamprey. Additional studies will be considered as more Pacific lamprey are available in the river to better understand the effects of Reclamation diversions on lamprey due to entrainment.

Yakima Basin “Rapid Assessments”

Background

Reclamation engaged in initial discussions with YN regarding the need to assess diversion structures in the Yakima basin for lamprey adult passage and juvenile protection concepts. These “Rapid Assessments” would entail the development of a team of lamprey and fish passage/protection experts participating in site visits to project facilities in the Yakima basin with the goal of developing site-specific concepts that could be implemented to provide passage for adult Pacific lamprey and protect juveniles from entrainment.

Update

In 2011, appropriate team members were discussed and preliminary contact was made with these possible team members from NOAA Fisheries, YN, USGS, TSC and other Reclamation offices. The successful pilot year of the radiotelemetry study discussed in the previous section provides valuable information to this Rapid Assessment effort.

Future Plan

Reclamation will work with team members to do Yakima Basin projects site visits in 2012. The team will discuss, develop, and document possible concepts for passage and protection at each site. These concepts should be informed by the current work in the Yakima basin evaluating adult movement patterns and behavior, as well as the juvenile canal sampling efforts.

Fish Screen Materials Evaluation

Study Lead – U.S. Geological Survey

Matt Mesa
Research Biologist
Western Fisheries Research Center, Columbia River Research Laboratory
Cook, WA

Interagency Agreement R10PG17414

Background

Reclamation is one of several funding partner agencies contributing to a USGS-led study of how juvenile lamprey move through diversion systems, what factors influence entrainment and entrapment of juveniles, and to provide information for the development of criteria for passage and protection of lamprey. Other partner funding agencies include FWS, USGS, CTUIR and CRITFC. In addition, YN, CTUIR and CRITFC have encouraged Reclamation to continue funding this study as part of Fish Accords commitments.

The study objectives are: 1.) Document the general passage characteristics of juvenile lamprey over selected screen types in the laboratory; 2.) Estimate the rate of entrainment of juvenile lamprey at various screen sites in the field; 3.) Document the general passage characteristics of juvenile lamprey experimentally released over screens in the field; and 4.) Develop velocity and operational criteria for the safe and effective passage of juvenile lamprey at different types of diversion screens in the Columbia River Basin.

USGS began work on this study in April, 2010. Personnel were put in place, supplies and materials purchased, and experiments focusing on the first part of Objective 1 conducted. Entrainment, impingement, and injury of ammocoetes exposed to different screen panels at an approach velocity of 0.4 ft/s (current salmonid screening criteria) were evaluated. No sweeping velocity component was used in this initial work.

Update

A draft report of the initial work has been submitted for journal review; the abstract is presented here:

Effectiveness of Common Fish Screen Materials to Protect Lamprey Ammocoetes

Brien P. Rose and Matthew G. Mesa

Abstract: Pacific lamprey (*Entosphenus tridentatus*) populations in the Columbia River Basin have declined and understanding lamprey passage issues at irrigation diversions is a high priority for their recovery. For this reason, we tested the effectiveness of five common fish screen materials (interlock [IL], vertical bar [VB], perforated plate [PP], and 12 and 14 gauge wire cloth [WC12 and WC14]) to protect lamprey ammocoetes in a series of laboratory tests. When fish (from 28–153 mm in length) were exposed for 60 min to screen panels perpendicular to an approach velocity of 12 cm/s in a recirculating flume, the percentage of ammocoetes entrained was 26% for the IL, 18% for the PP, 33% for the VB, 62% for the WC14, and 65% for the WC12. For all screens, most fish were entrained within the first 15-20 min. Fish length significantly influenced the odds of entrainment for all screen types, with PP, VB, and IL screens offering complete protection for fish greater than about 50-65 mm and WC14 and WC12 protecting fish greater than about 90-110 mm. Fish of all sizes repeatedly contacted and became impinged on the screens, with the frequency of impingement events increasing during the first 5 min and becoming relatively stable thereafter. Impingements were highest on the IL screen (range = 36-62%), lowest on the WC14 and WC12 screens (range = 13-31%), and intermediate on the PP and VB screens (range = 23-54%). However, the WC14 and WC12 screens had fewer and larger fish remaining as time elapsed because so many were entrained. For all screen types, injuries were rare and minor, and no fish died after 24-h of post-test holding. Our results represent a significant first step toward development of design and operational criteria for fish screens to protect juvenile lamprey.

Future Plan

Reclamation intends to continue funding of this study in FY12. FY10 and FY11 work focused on initial testing, reporting, and design and planning for future work. USGS is preparing to move into the second phase involving more lab tests evaluating entrainment, impingement, etc., of lamprey exposed to different screen types. The effort is scaling up to make tests more realistic by adding a sweeping velocity component, a bypass, and varied screen angles. This work requires design, construction, and implementation of a large screen testing tank. This device will allow testing with a high degree of ecological realism and experimental replication and control.

Physical and Behavioral Juvenile Guidance Study

Study Lead – Reclamation PNRO

Stephen Grabowski, Retired and Sue Camp, Fish Biologist
Ecosystems Analysis Group
Boise, ID

Background

In 2009 and 2010 Reclamation performed a study to evaluate screen materials as well as some potential physical and behavioral guidance devices that could potentially reduce the diversion of juvenile Pacific lamprey into canals. This study was funded through Reclamation's Science and Technology Program and undertaken by Reclamation staff.

Update

The final report is attached as Appendix E and a summary is provided here:

Response of Pacific Lamprey Ammocoetes and Macropthalmia to Several Physical and Behavioral Guidance Devices

Stephen Grabowski

The focus of this research project was to evaluate some potential physical and behavioral guidance devices that could potentially reduce the diversion of juvenile Pacific lamprey into canals. Wedge wire screen and woven wire screen materials were tested. The wedge wire screen met NOAA Fisheries criteria for fry. Woven wire was 4.5-12, or 5/32-inch opening. This size of woven wire screen is commonly used on rotating drum fish screens at juvenile fish bypass systems in the Yakima Basin. Other potential technologies tested include an air bubble curtain similar to that tested in 2009, and a low voltage high intensity light bar array. Lastly a combination of the air bubble curtain and the low voltage high intensity light bar array at night was tested.

Figure 6 – Flume for testing lamprey juvenile guidance

Guidance devices were tested in a flume constructed to accommodate a variety of devices for testing. The flume was split into two channels at the far end and the flume design allowed a physical or behavioral guidance device to be placed in front of one of two channels. Water was pumped through the flume and Pacific lamprey ammocoetes or macropthalmia were introduced, in groups of ten, into the head of the test flume with one of the various guidance devices in place in front of one of the channels. For each trial, the fish were subsequently recovered at the far end of the flume and enumerated to compare the number successfully guided to the desired channel to the number that passed the barrier device and was "entrained". The wedgewire screen and wovenwire screen material meeting current NOAA Fisheries criteria for salmonids both successfully guided lamprey ammocoetes to the desired channel. Though some trials indicated the air bubble curtain may show promise at guiding lamprey to the desired channel, the overall test results indicated it did not successfully guide the fish. Manipulations of the water velocities and bubble configurations could lead to better results with this device. A low voltage high intensity light bar array was inconclusive, with 40% of fish being "guided" during day time trials, and 56% guided during night time trials. More manipulation of the light bar array and further study may be able to elicit a response in lamprey. Likewise, the combination of high intensity lights with the air bubble curtain resulted in about the same number of lamprey guided as not.

Pacific lamprey ammocoetes exhibited some interesting behavior both in the holding tanks and in the test flume. They appeared to be very sensitive to disturbance in the holding tank, such as when they were dislodged out of the substrate and netted for testing in the flume. The holding tanks for the ammocoetes had a substrate of Quickrete Play Sand about 3 inches deep to allow them to burrow. After the substrate was disturbed and fish collected to introduce into the flume, they relatively quickly burrowed back into the substrate. They generally burrowed head first, often at a shallow angle rather than vertical. The intense sensitivity to movement and vibration in the holding tank indicates additional devices could be tested that capitalize on this behavior to guide lamprey away from diversions.

Future Plan

This study is completed. Based on observations during this study, Reclamation may pursue additional funding through the Science and Technology program to develop and test additional behavioral guidance devices such as alternatives using vibration to deter lamprey. However, current efforts are focused on further evaluating the extent of lamprey entrainment into diversions before further study of guidance devices is pursued.

Swimming Performance Study

Study Lead – Reclamation Technical Service Center
Zachary Sutphin
Fish Biologist
Fisheries and Wildlife Resources Group
Denver, CO

Background

In 2009, Reclamation completed a study to gain basic knowledge pertaining to the swimming capabilities of Pacific lamprey related to possible effects from diversions and fish screens. The objective of this study was to measure the swimming performance of larval Pacific lamprey over the entire range of swimming speeds (sustained, prolonged and burst speeds) they may be forced to utilize in their natural environment.

Update

The final report is attached as Appendix F, and the abstract is presented here:

Swimming Performance of Larval Pacific Lamprey (Lampetra tridentata)
Charles Hueth and Zachary Sutphin

Abstract: Laboratory experiments were conducted to measure the prolonged-sustained and burst swimming speeds of wild larval (ammocoete) Pacific lamprey (*Lampetra tridentate*). Prolonged-sustained speeds were measured using an annular variable speed swimming chamber and burst speeds were determined using a swimming raceway and digital video analysis. During prolonged-sustained swimming experiments, the mean length of time lamprey (72 – 143 mm TL) were able to swim in the chamber ranged from 43.0 min when exposed to a velocity of 10 cm/s, to 0.4 min when exposed to 50 cm/s. The burst swimming speeds of lamprey tended to increase as length increased from 107 to 150 mm TL, and ranged from 33.3 to 75.0 cm/s. Our estimates of the overall swimming performance of this life-stage are the first reported for this species, and can provide important information when developing approach velocities and infrastructure to improve lamprey passage while minimizing entrainment loss.

Future Plan

This study is complete. Results of this study will be used to inform further efforts to evaluate and address juvenile lamprey issues.

Reclamation Lamprey Plan

Background

Paraphrasing from the Accords, Reclamation agreed to jointly, with the Tribes, develop a lamprey implementation plan for Reclamation projects, and the plan will include priority actions and identification of authority and funding issues. It will be updated annually based on the most recent information, and Reclamation will seek to implement recommended actions from the implementation plan.

Implementation Plan

Reclamation is working with CTUIR, YN and other partners to implement recommendations in the Assessment for further study or actions that may be taken to reduce effects to Pacific lamprey. First, further studies, as described in this report, are in progress to better understand the effects of Reclamation projects on lamprey. As these studies increase our knowledge, an implementation plan is being developed in collaboration with partners to identify and prioritize actions needed to address Pacific lamprey effects.

Reclamation has identified funds of approximately $400,000 for Fiscal Year (FY) 2012, for lamprey activities. Activities have been identified for FY2013-FY2016 for similar funding levels, but actual out-year funding will depend upon appropriations, activity identification and prioritization, and other factors. Table 2 represents a draft plan of studies and anticipated actions based on the knowledge of the species and Reclamation effects at this time. Several agreements with partners are in place for continuing work on the activities as summarized in the "Lamprey Activities Summary", and additional mechanisms to conduct lamprey work are continuously being refined through collaboration with the tribes and other partners as opportunities develop. Where possible, the mechanism for funding and/or the partner primarily responsible for each activity is identified for 2012. This plan will be revised with input from YN, CTUIR, and CRITFC annually as our knowledge develops. Implementation activities in 2013-2016 represent placeholders for passage improvement and entrainment protection activities that Reclamation will seek to implement if the need is identified.

Table 2. Reclamation plan for lamprey activities 2012-2016.

		FY2012		FY2013	FY2014-FY2016
	ACTIVITY	Description	Mechanism/Partner	Description	Description
YAKIMA RIVER BASIN	Yakima Project Juvenile Investigations	Continue canal surveys - Prosser, Sunnyside, Roza, Wapatox	YN Coop Agreement YN Coop Agreement TSC Agreement	Continue Canal Surveys Entrainment study	If needed, continue canal surveys and/or specific entrainment study or monitoring
	Yakama Nation Propogation Support	Equipment purchase and labor support	YN Coop Agreement	Propogation operation support	Propogation operation support
	Water Quality Monitoring	Support Yakama Nation water quality efforts	YN Coop Agreement	Support water quality efforts	Support water quality efforts
	Yakima River Radiotelemetry Adult Movement Study	Continue FWS study Adult lamprey collection Improve adult holding capability at Prosser Dam	FWS Interagency Agreement YN Coop Agreement YN Coop Agreement	Continue FWS Study Continue lamprey collection	Telemetry monitoring Continue Lamprey collection
	Yakima Basin Adult Passage Improvements	Rapid Assessments: Sunnyside and Prosser	Staff time and travel, agreements if needed	Design/Install LPS - Prosser?	Design/Install as informed by previous studies
	Yakima Basin Juvenile Protection			Additional Rapid Assessments	Design/Install as informed by previous studies
UMATILLA RIVER BASIN	Umatilla Project Juvenile Investigations	Continue canal surveys - West Extension, Feed Canal, Maxwell	TSC Service Agreement and Staff time/travel	Continue canal surveys or specific entrainment study	If needed, continue canal surveys or specific entrainment study
		Juvenile migration and timing studies	TSC/CTUIR/NOAA Fisheries, Supplies	Continue juvenile migration studies	Juvenile migration monitoring
		Entrainment Study	TSC Service Agreement/PN Staff	Additional entrainment study, if needed	
	Umatilla Basin Adult Movement Monitoring (LPS Monitoring)	Support CTUIR monitoring of adult movements	NOAA Fisheries Interagency Agreement	Continue support adult movement study	Continue support adult movement study
	Umatilla Basin Adult Passage Improvements	Modify Feed Diversion LPS	Umatilla office staff/supplies	Modify other passages, if needed, and/or develop entrainment protection.	Modify other passages, if needed, or seek to develop entrainment protection.
	Umatilla Basin Juvenile Protection				
REGIONAL	Entrainment Protection Development	Funding support USGS study	USGS Interagency Agreement	Funding support USGS study	Entrainment protection
	Administration and Reporting	Planning, Administration, Coordination, Collaboration	Staff time and travel	Planning, Administration, Coordination, Collaboration	Planning, Administration, Coordination, Collaboration
	Research	Science &Technology (S&T) Proposal - in-river juvenile sampling techniques	CTUIR and TSC proposal to S&T	Proposal to S&T Program	Proposal to S&T Program

In the Yakima River Basin, the strategy is to first gain a better understanding of the issues and develop methods to measure them. The current focus is on the furthermost downstream facilities (below Roza dam) for more intensive study in the near term and we anticipate doing more work in the upper basin in out years. Reclamation plans to continue funding YN through a cooperative agreement to conduct canal surveys and additional investigations and to provide support to propogation, water quality monitoring, and radiotelemetry monitoring. The interagency agreement with FWS will continue to be funded through 2013 and possibly beyond if necessary to continue to monitor adult and juvenile lamprey movements relative to Reclamation facilities. Rapid Assessments will be initiated in 2012 and continued in 2013 to develop a process for evaluating concepts to provide adult lamprey passage and entrainment protection as determined necessary by the results of these studies. We anticipate possible design/installation of adult lamprey passage structures, if needed (and if funding available) beginning in FY2013. Information from ongoing studies will be used to prioritize projects for adult passage and to develop lamprey passage designs and placement. In addition, Reclamation will provide technical support through staff time from the various Reclamation offices involved in these efforts.

In the Umatilla River Basin, Reclamation plans to continue to work closely with CTUIR to accomplish continued canal surveys/salvage, and to monitor adult movements and adult passage efficiency. Additional entrainment studies will focus on better understanding juvenile migration patterns and behaviors in the basin with a focus on implications for Reclamation projects. In FY2012, Feed Dam passage will be modified because a need was identified to better protect the structure from debris. In out years, modifications and/or design/implementation of passage and entrainment protection measures will be planned as appropriate to address issues as identified through studies.

From a Regional perspective, Reclamation will continue to fund the USGS study to study the effects of diversions on Pacific lamprey. We will collaborate to tie this laboratory study to field studies, which will facilitate a better understanding of the mechanism of juvenile lamprey entrainment and identify possible solutions where needed. Reclamation also remains committed to continued planning, administration, coordination and collaboration on Pacific lamprey issues through development and administration of funding agreements, participation in interagency meetings and Pacific lamprey workgroup meetings, field studies, continued communications with all partners, and other activities. A key part of communication in FY2012 will be increased outreach with Reclamation's customers, such as the irrigation districts and municipalities that operate/maintain Reclamation facilities or that have contracts for water, so that they are considered more active partners in our lamprey activities.

Finally, an opportunity exists within Reclamation to augment programmed funding with additional money from Reclamations Science and Technology (S&T) program. This program is a Reclamation-wide competitive, merit-based research and development program that is focused on innovative solutions for issues facing Reclamation water and facility managers and western water stakeholders. Funding is available on an annual basis through application to the program; applications are submitted by Reclamation personnel but are highly focused on effective partnerships. Reclamation and CTUIR are developing a proposal in 2012 to submit an application to research more effective juvenile sampling techniques. Other research proposals may be developed and submitted as other areas are identified where collaborative research would be a good fit for this program to leverage additional funding. Any additional research funded from the S&T Program would be performed by TSC and our research partners.

Authority and Funding Issues

The previous section outlines Reclamation's plan for the next few years to continue working with partners to understand effects to Pacific lamprey from Reclamation projects and to seek to develop solutions to address those effects. This section is a discussion of authority and funding issues which may affect implementation of the plan.

Reclamation's authority for lamprey activities is primarily through **The Fish and Wildlife Coordination Act, 16 U.S.C. § 661**: "For the purpose of recognizing the vital contribution of our wildlife resources to the Nation, the increasing public interest and significance thereof due to expansion of our national economy and other factors, and to provide that wildlife conservation shall receive equal consideration and be coordinated with other features of water-resource development programs through the effectual and harmonious planning, development, maintenance, and coordination of wildlife conservation and rehabilitation for the purposes of sections 661 to 666c of this title in the United States, its Territories and possessions, the Secretary of the Interior is authorized (1) to provide assistance to, and cooperate with, Federal, State, and public or private agencies and organizations in the development, protection, rearing, and stocking of all species of wildlife, resources thereof, and their habitat, in controlling losses of the same from disease or other causes…."

Reclamation is using this authority to carry out studies and planning of Pacific lamprey issues at Reclamation projects. Reclamation does not have authority to make any operational or structural modification decisions at non-Reclamation facilities.

Activities such as studies, research, and planning (including most lamprey activities in this report) are primarily currently funded by Reclamation's Columbia/Snake Salmon Recovery Office (CSRO) in the Pacific Northwest Regional Office in Boise, Idaho. Reclamation's field offices in the Umatilla and Yakima River Basins have also contributed funding and other support. Reclamation's CSRO is responsible for implementation of Reclamation's commitments under the Federal Columbia River Power System (FCRPS) Biological Opinion and all related activities, such as the Fish Accords. Funding for lamprey activities is identified from the same budgets as Reclamation’s commitments to Endangered Species Act (ESA) listed species covered under the FCRPS Biological Opinion (salmon and steelhead species).

Summary

Since the Fish Accords were signed in 2008, Reclamation has been working with YN, CTUIR, CRITFC, and other partners to learn more about how Reclamation projects may affect Pacific lamprey, identify issues, and begin developing and implementing solutions. This report summarizes that Pacific lamprey work to date with a focus on work completed in 2011.

In 2011 Reclamation participated in a number of collaborative activities such as meetings with CRITFC, YN, and CTUIR at staff and management levels, participated in lamprey information sharing opportunities with the USACE to enhance interagency cooperation, made efforts to educate water user groups and irrigation districts on lamprey issues, and participated actively with the LTWG. Reclamation also finalized the Assessment of Reclamation project’s effects on Pacific lamprey and incorporated the recommendations into additional work. Updates are provided on studies and/or activities in which Reclamation is a participating partner such as Umatilla Basin passage structures, juvenile sampling efforts in both Umatilla Basin and Yakima Basin canals, the Yakima Basin adult lamprey radiotelemetry study, Yakima Basin rapid assessments, the fish screen materials evaluation study, a juvenile guidance study, and a swimming performance study.

The plan for FY2012-2016 is to continue this work through various instruments of funding and technical participation to implement studies and activities for Pacific lamprey. Reclamation plans to collaborate with YN, CTUIR and CRITFC to update this plan annually to continue meeting Pacific lamprey commitments as specified in the Accords.

APPENDIX A

Assessment of U.S. Bureau of Reclamation Projects in the Columbia River Basin: Effects on Pacific Lamprey (*Lampetra tridentata*)

RECLAMATION
Managing Water in the West

Assessment of U.S. Bureau of Reclamation Projects in the Columbia River Basin: Effects on Pacific Lamprey (*Lampetra tridentata*)

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Pacific Northwest Regional Office, Boise, Idaho

January 2012

U.S. Department of the Interior

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

RECLAMATION
Managing Water in the West

Assessment of U.S. Bureau of Reclamation Projects in the Columbia River Basin: Effects on Pacific Lamprey (*Lampetra tridentata*)

Regional Resource & Technical Services

Ecosystems Analysis Group

Report prepared by

Steven Grabowski, Fish Biologist (Retired)

Susan L. Camp, Fish Biologist

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Pacific Northwest Regional Office, Boise, Idaho

January 2012

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1.0 INTRODUCTION

The Bureau of Reclamation (Reclamation), along with Bonneville Power Administration, and U.S. Army Corps of Engineers (Action Agencies) that operate the Federal Columbia River Power System (FCRPS) entered into a Memorandum of Agreement in 2008 with several Columbia River basin states and Tribes, the 2008 Columbia Basin Fish Accords. The Accords include agreements to implement and fund numerous fisheries and habitat-related actions to improve fish survival in addition to those already prescribed in the RPA in the 2008 NOAA Fisheries Biological Opinion on the FCRPS (NOAA Fisheries 2008). Several actions in the 2008 Columbia Basin Fish Accords dealt specifically with Pacific lamprey (*Lampetra tridentata*).

In the 2008 Columbia Basin Fish Accords with the Treaty Tribes, the action agencies each agreed to pursue or implement numerous actions to address and potentially reverse the recent decline in Pacific lamprey numbers in the basin. Reclamation agreed to the following two commitments:

1. Beginning in 2008, and concluding in 2010, Reclamation will conduct a study, in consultation with the Tribes, to identify all Reclamation projects in the Columbia Basin that may affect lamprey. The study will also investigate potential effects of Reclamation facilities on adult and juvenile lamprey, and where appropriate, make recommendations for either further study or for actions that may be taken to reduce effects on lamprey. The priority focus of the study will be the Umatilla and Yakima projects and related facilities.

2. Beginning in 2008, Reclamation and the Tribes will jointly develop a lamprey implementation plan for Reclamation projects as informed by the study above, the tribal draft restoration plan, and other available information. The plan will include priority actions and identification of authority and funding issues. It will be updated annually based on the most recent information. Reclamation will seek to implement recommended actions from the implementation plan (2008 Columbia Basin Fish Accords, Memorandum of Agreement between the Three Treaty Tribes and FCRPS Action Agencies, May 2008).

This report documents the assessment activities undertaken to satisfy the first commitment to identify Reclamation projects that may affect Pacific lamprey, investigate potential effects, and make recommendations for further study or actions. This document will serve to inform the Reclamation plan in the second commitment that is also in development. A separate, but closely-related, effort has been funded by Reclamation's Science and Technology Program at the Technical Service Center in Denver and is providing some supporting information on

Pacific lamprey issues such as adult and juvenile passage and guidance techniques. Additional work has taken place since this document was released in Draft, including sampling in Reclamation canals in the Yakima and Umatilla basin, completion of reports for the juvenile guidance study, initiation of a radiotelemetry study tracking adult movements in the Yakima Basin, and development of workplans to continue lamprey work in these basins.

Consistent with the Accords commitment, Reclamation focused this assessment on its projects in the Yakima River basin in south-central Washington and in the Umatilla River in northeastern Oregon.

This assessment:

- Describes the historic abundance and distribution of Pacific lamprey in the Columbia River and tributaries;
- Describes the current status and trend of Pacific lamprey in the Columbia River basin;
- Describes, in general terms, factors affecting Pacific lamprey;
- Describes, in general terms, opportunities for addressing limiting factors, particularly adult and juvenile passage and entrainment issues;
- Describes Reclamation and non-Reclamation water diversion and storage projects in the Yakima and Umatilla river basins and conditions at the projects that may affect lamprey;
- Discusses possible effects including the presence, if any, of Pacific lamprey, and conditions that might affect adult and juvenile Pacific lamprey passage;
- Makes recommendations for further study or discusses some potential opportunities and limitations for addressing identified Pacific lamprey issues at Reclamation water diversion projects;
- Describes Reclamation projects and planned activities in other basins throughout the Columbia River basin that may affect lamprey.

This report also describes some near-term future actions Reclamation either is implementing or proposes to implement to address adult upstream and juvenile downstream Pacific lamprey passage issues. Reclamation is committed to continued cooperation and collaboration with ongoing tribal Pacific lamprey restoration efforts and to participation in broader basin-wide Pacific lamprey restoration activities and initiatives where Reclamation has existing authority and participation is appropriate. Reclamation also emphasizes the importance of our collaborative relationships with the Yakama Nation and the Confederated Tribes of the Umatilla Reservation in these efforts.

To provide a more complete picture of potential effects of water diversion projects basin-wide on migrating or rearing Pacific lamprey, Reclamation worked with tribal leaders, biologists and others to include information about non-Reclamation projects as well. At many of these structures there is overlap of operation or maintenance responsibilities of fish protection structures with Reclamation and other agencies.

Water diversion and water storage projects reviewed in this assessment are:

- Yakima Basin
  - Yakima River Reclamation Diversion Dams
    - Prosser Diversion Dam
    - Sunnyside Diversion Dam
    - Roza Diversion Dam
    - Easton Diversion Dam
  - Yakima River Non-Reclamation Diversion Dams
    - Horn Rapids (Wanawish) Diversion Dam
    - Wapato Diversion Dam
    - Town Diversion Dam
  - Naches/Tieton Rivers Reclamation Diversion Dams
    - Wapatox Diversion Dam
    - Yakima-Tieton Diversion Dam
  - Naches/Tieton Rivers Non-Reclamation Diversion Dams
    - Naches-Cowiche Diversion Dam
    - Gleed Diversion Dam
    - City of Yakima Diversion Dam
    - Naches-Selah Diversion Dam
  - Yakima Basin Reclamation Storage Facilities
    - Kachess Dam
    - Keechelus Dam
    - Tieton Dam
    - Clear Creek Dam

        - Bumping Lake Dam
- Umatilla Basin
    - Umatilla River Reclamation Diversion Dams
        - Three Mile Falls Dam
        - Maxwell Diversion Dam
        - Feed Canal Diversion Dam
    - Umatilla River Non-Reclamation Diversion Dams
        - Dillon Dam
        - Westland Diversion Dam
        - Stanfield Diversion Dam
    - Umatilla Basin Reclamation Storage Facility
        - McKay Dam
- Other Columbia River Subbasins
    - Deschutes Project Facilities (Deschutes River Basin)
    - Crooked River Project Facilities (Deschutes River Basin)
    - Wapinitia Project Facilities (Deschutes River Basin)

2.0 APPROACH

Since 2008, Reclamation staff and contractors have participated in numerous federal agency and Tribal workshops and meetings that considered and discussed the current condition of Pacific lamprey populations in the Columbia River basin, as well as potential actions to restore these populations. Reclamation staff has participated in numerous meetings and correspondence with Tribal, state and other federal biologists in various venues to discuss and develop approaches to provide improved upstream passage for adult Pacific lamprey and to study potential methods to guide both actively and passively downstream migrating juveniles from being entrained into irrigation canals at diversion structures. Some of this work was completed under the above-mentioned Science and Technology Program. The USGS Columbia River Research Laboratory at Cook, Washington, also has some research on Pacific lamprey entrainment protection underway, partly funded by Reclamation. In 2009 Reclamation did a study to gain basic knowledge pertaining to the swimming capabilities of Pacific lamprey related to possible effects from diversions and fish screens (Sutphin and Hueth 2010). In 2009 and 2010 Reclamation performed a study to evaluate screen materials as well as some potential physical and behavioral guidance devices that could potentially reduce the diversion of juvenile Pacific lamprey into canals (Grabowski 2010). Additionally, since release of the draft of this document, Reclamation has completed additional work as recommended in the Draft including sampling in Reclamation canals for lamprey ammocoetes and continued funding of the studies mentioned above. Updates are available in Reclamation's 2011 Annual Report (Reclamation 2012).

In the Yakima Basin, Reclamation staff has discussed the issue of the adult and juvenile Pacific lamprey passage issues and potential solutions with fisheries biologists from the Yakama Nation and other federal and state agencies. In May 2010, Reclamation staff participated with Tribal and other federal fisheries biologists in a visit to four irrigation diversion structures in the lower Yakima River basin to assess Pacific lamprey passage issues and in particular to assess the opportunities for U.S. Fish and Wildlife Service fisheries biologists to install radio-tracking equipment on diversion dams to track radio-tagged adult Pacific lamprey. The U.S. Fish and Wildlife Service, Mid-Columbia Fisheries Resources Office, Leavenworth, Washington, is funded through the Yakama Nation, Reclamation, and others to initiate a Pacific lamprey radio-tagging and tracking study in the Yakima Basin, which is expected to continue for several years. This study should provide necessary additional information to determine when and where adult Pacific lamprey approach the diversion structures and if it is practical and feasible to install lamprey passage systems (LPSs or Lamprey Passage Structure (LPS)s) at these lower Yakima River projects to facilitate upstream migration of adult Pacific lamprey.

In August, 2010 Reclamation staff conducted additional site visits to upper Yakima River Reclamation and non-Reclamation water diversion and storage projects. Reclamation staff and tribal biologists have visited water diversion facilities in the Umatilla River occasionally during the past two years.

3.0 PACIFIC LAMPREY STATUS IN COLUMBIA RIVER BASIN

Pacific lamprey are not listed under the Endangered Species Act, although this and three other species of lamprey were petitioned for listing on 23 January 2003 by the Siskiyou Regional Education Project and 10 other organizations. The U.S. Fish and Wildlife Service declined to list Pacific lamprey, based in part on insufficient data with which to conduct an adequate status review and the inability to define a listable entity (USFWS 2004). Populations of Pacific lamprey in the Columbia River basin continue to decline; state and federal agencies and Columbia River Tribes have serious concerns regarding the species continued existence. Pacific lamprey are culturally important to Native Americans as a source of food and medicine (Close at al 1995). They also provide numerous ecologically important benefits to aquatic ecosystems, such as a food source for juvenile salmon, birds and mammals, and historically were a source of marine-derived nutrients that helped sustain aquatic and terrestrial ecosystems (Lewis 2009).

A decline in Pacific lamprey abundance and distribution throughout California, Oregon, Washington, and Idaho is noted in Luzier et al (2011), though uncertainty was high due to lack of historical records. Current occupancy appeared to be significantly smaller than historic range extent. Figure 1 depicts the historic range and decline of Pacific lamprey illustrated as the ratio of current distribution to historic.

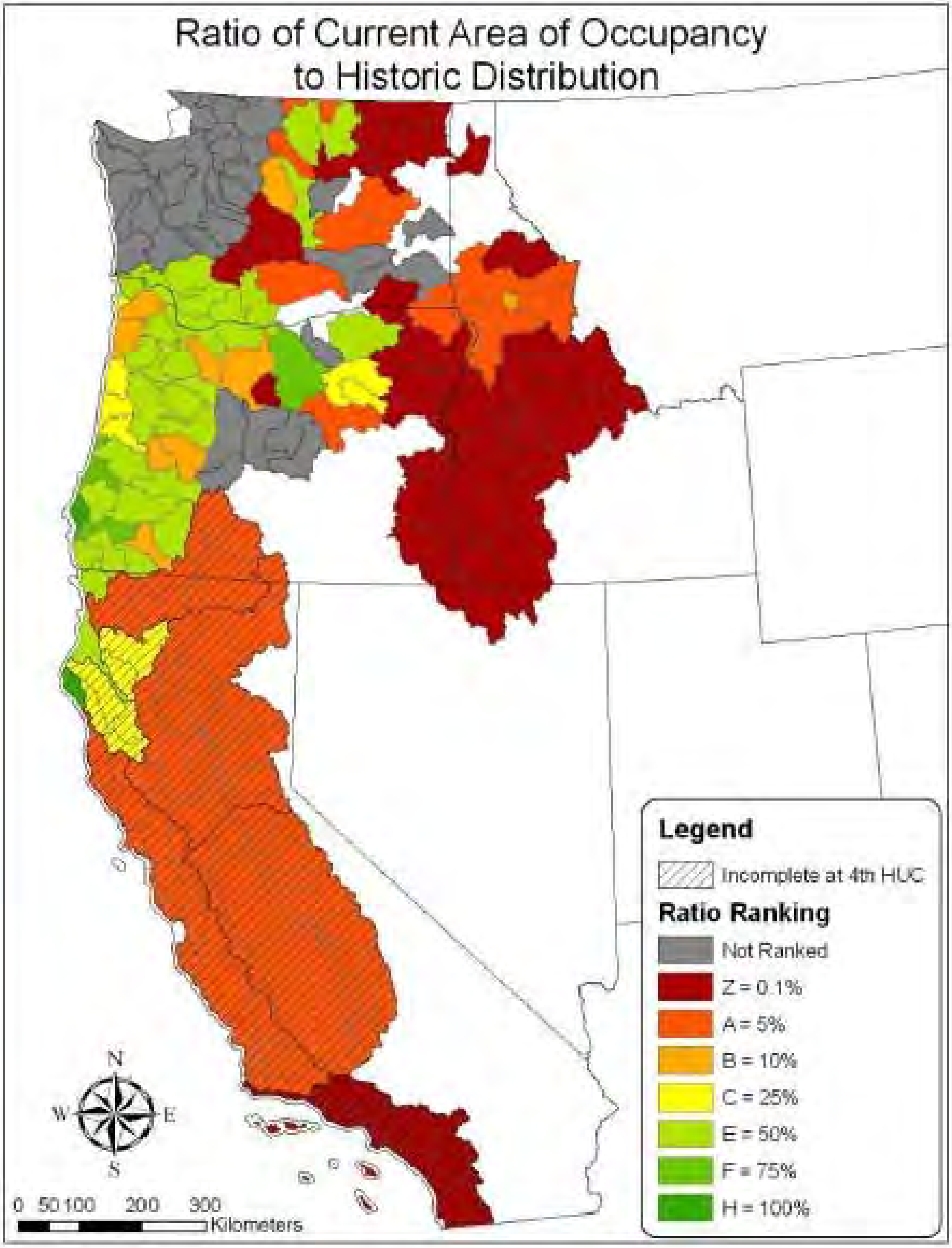

Figure 1 - Historic distribution of Pacific lamprey illustrated as a ratio of current and historic area of occupancy. (Luzier et al 2011)

3.1 Pacific Lamprey Abundance in the Mainstem Columbia River

3.1.1 Adult Abundance

The number of adult Pacific lamprey returning to the Columbia Basin historically is estimated to be in the millions (Luzier et al 2011). In recent years Pacific lamprey abundance in the Columbia Basin has declined substantially as indicated by the adult count at Bonneville Dam. Figure 1 depicts the numbers of adult Pacific lamprey counted at Bonneville Dam from 1939 to 2010, while Figure 2 shows Pacific lamprey counts for the more recent period 1997 to 2010. No count data were available from 1970 to 1996. The number of adult Pacific lamprey at Bonneville Dam provides a useful index by which to compare Pacific lamprey numbers over the years, but due to counting techniques changing over time, the numbers may be substantially underestimated before 1970. Figure 1 suggests that Pacific lamprey numbers have fluctuated widely over the time period; the U.S. Army Corps of Engineers (2008) noted that the reported counts at Bonneville Dam should be considered as an approximation of trends only, since adult Pacific lamprey are difficult to count, they are more likely to pass at night, and some counting methods have changed over the years. Figure 3 shows both the overall reduction in the adult Pacific lamprey counts at upriver McNary Dam and the decline in recent years (2000-2010) that is similar to the decline noted at Bonneville Dam from 2000 to 2010.

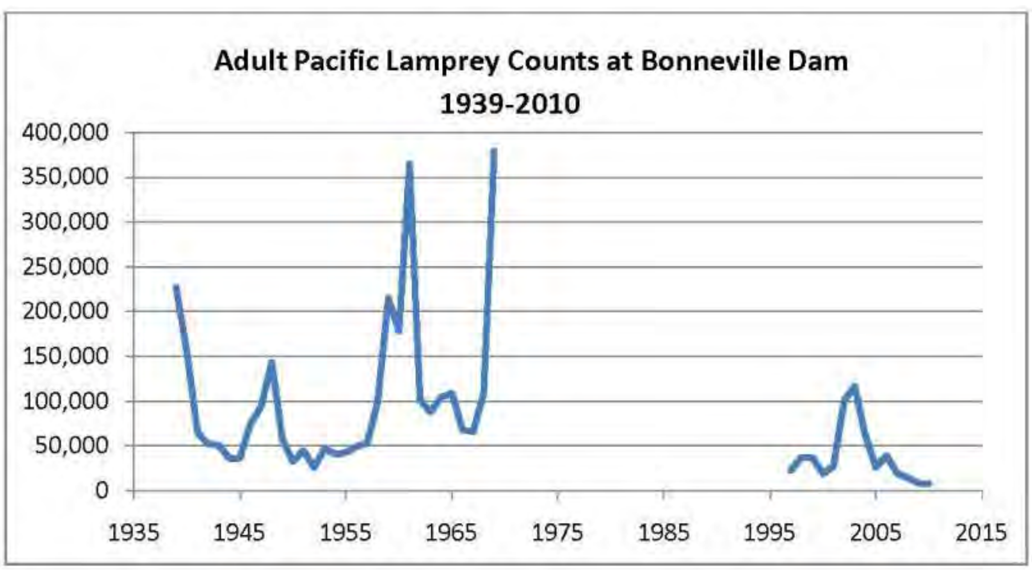

Figure 2. Count of adult Pacific lamprey at Bonneville Dam from 1939 to 2010. No count data

were available from 1970 through 1996. Counting methods and effort was not likely consistent throughout the time period. Source: U.S. Army Corps of Engineers (2009).

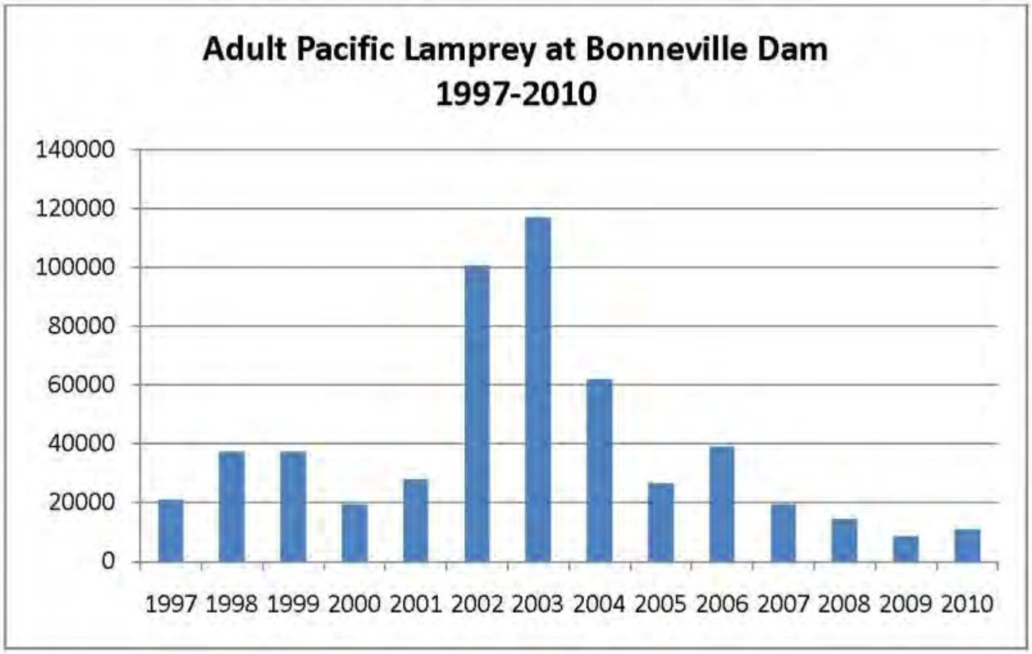

Figure 3. Count of adult Pacific lamprey at Bonneville Dam from 1997 to 2010. Source: U.S. Army Corps of Engineers (2009) and Columbia River DART.

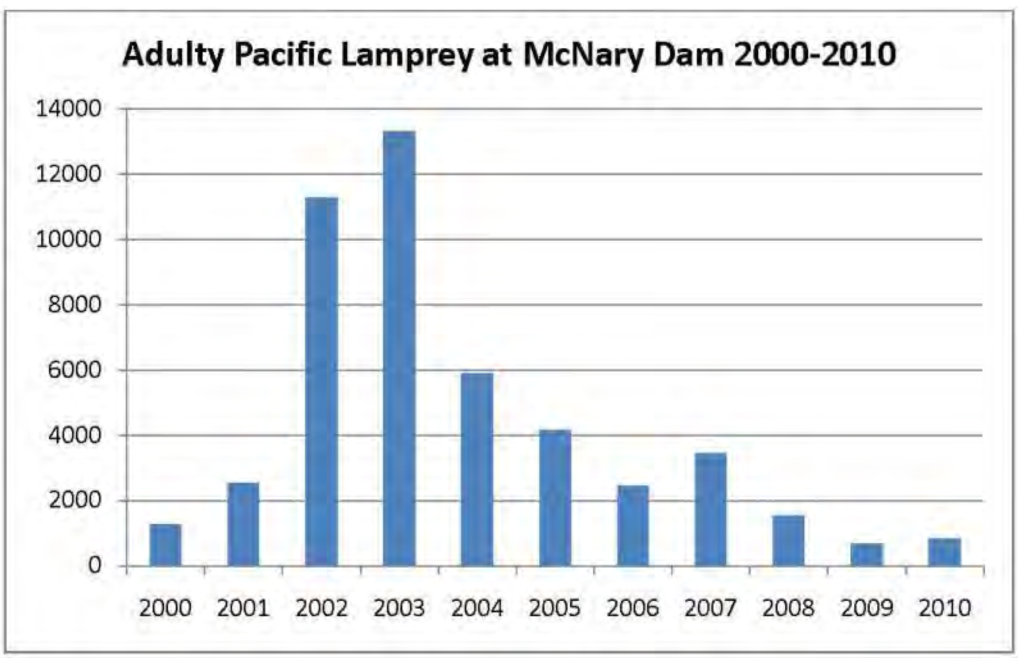

Figure 4. Count of adult Pacific lamprey at McNary Dam from 2000 to 2010. Source: U.S. Army Corps of Engineers (2009) and Columbia River DART.

Radio-tagged adult Pacific lamprey released below Bonneville Dam from 1997 to 2000 were tracked upstream through hydropower projects in the lower Columbia River. Passage efficiency for the fish that approached Bonneville Dam was less than 50 percent, while it ranged from 50 to 82 percent at The Dalles Dam and less at John Day Dam (Moser et al. 2002). In 1997-1999, no tagged Pacific lamprey were detected at McNary Dam, although in 2000, 13 of 23 fish detected at John Day Dam were also detected at McNary Dam. These data suggest that there is approximately 50 percent decrease in migrating adult Pacific lamprey abundance in passage through each hydropower project. This could result from (at the time of the study) the difficulty of Pacific lamprey passing through fish ladders designed for adult salmon and steelhead, mortality associated with predation, an artifact of in-river residence of lamprey over winter, or migration into tributaries such as the Deschutes River.

3.1.2 Juvenile Abundance

Some limited information is available on juvenile Pacific lamprey at Columbia River hydropower projects. For this assessment Reclamation will focus on juvenile lamprey counts reported for Bonneville Dam and McNary Dam. The Fish Passage Center's website[1] provides juvenile passage information for years 1997 to 2010. Table 3 provides a summary of this information for Bonneville Dam Powerhouses 1 and 2, and McNary Dam. For Bonneville Dam, the FPC reports counts for juvenile silver lamprey and juvenile brown lamprey, the latter of which occur in miniscule numbers compared to juvenile silver lamprey. Juvenile silver lamprey most likely refers to outmigrating Pacific lamprey macropthalmia. The brown juvenile lamprey could be either Pacific, or other lamprey species (*L. richardsoni* or *L. ayresii*) ammocoetes that are entrained in the flow (Chockley 2010). The time periods for which counts are reported varied widely and was not uniform for all the reported years. Because of the wide range of sampling dates noted for the juvenile lamprey observations, it would be unrealistic to attempt a rigorous analysis to compare juvenile lamprey numbers across years. However, it can be concluded that many more juvenile lamprey are counted at the Bonneville Dam Powerhouse 2 compared to Powerhouse 1, and number of juvenile lamprey is much greater at McNary Dam compared to Bonneville Dam. The highest number of juvenile lamprey occurred at McNary in 1999, followed by 1997, 2002, and 2008.

[1] http://www.fpc.org/lamprey/smp_lamprey_query.html

Table 1. Estimated number of juvenile lamprey counted at Bonneville and McNary dams from 1997 to 2010. Since the sampling period is not consistent from year to year, the counts are not directly comparable. The numbers are shown simply to illustrate annual variation.

	Juvenile Lamprey					Juvenile Brown Lamprey							
	BON-PH1		BON-PH2			BON-PH1		BON-PH2				McNary Dam	
Yr	Count dates	Count	Count dates	Count	Total	Count dates	Count	Count dates	Count	Total	Grand total	Count dates	Count
1997	20Mar-18Jun	105	1 May-15Sep	154	259						259	5Apr-14Dec	5885
1998	12Mar-7Jul	43	8Apr-17Jun	27	70	9-May	1			1	71	30Mar-15Dec	3770
1999	13Mar-1Oct	22			22	10-Oct	1			1	23	30Mar-15Dec	8585
2000	6Apr-22Jun	3	9Mar-10Oct	376	379	10Apr-3Aug	4	10Mar-26Sep	7	11	390	1Apr-30Nov	4171
2001			17Mar-8Oct	230	230			16Mar-21Sep	7	7	237	3Apr-10Dec	992
2002	14Jun-21Jul	2	12Mar-31Oct	538	540	11-Jun	1	11Apr-13Sep	10	11	551	3Apr-11Dec	5474
2003	8Apr-13Jun	14	11Mar-25Oct	791	805			21Mar-19Oct	7	7	812	3Apr-26Sep	2098
2004			3Mar-22Aug	875	875			7Apr-15Oct	6	6	881	3Apr-18Sep	1068
2005			2Mar-7Sep	621	621			28Jun-13Aug	3	3	624	3Apr-13Sep	2023
2006			2Mar-15Sep	1472	1472			4Jun-9Oct	10	10	1482	3Apr-9Sep	2094
2007			2Mar-20Oct	2228	2228			24Mar-24Sep	6	6	2234	3Apr-13Sep	844
2008			4Mar-26Oct	1242	1242			12Apr-28Sep	12	12	1254	3Apr-24Sep	5135
2009			3Mar-30Oct	2397	2397			14Mar-29Oct	19	19	2416	9Apr-1Oct	3636
2010			2Mar-17Sep	1511	1511			19Mar-1Oct	37	37	1548	7Apr-26Sep	3487

3.2 Pacific Lamprey Abundance in the Yakima River Basin

3.2.1 Adult Abundance

Historical counts of Pacific lamprey in the Yakima Basin are sparse; Wydoski and Whitney (2003) noted that Pacific lamprey occur in the Yakima Basin, but that "[f]ewer than 15 adult Pacific lamprey were observed at Prosser or Roza Dams or Chandler Juvenile Fish Facility on the Yakima River since 1992." Adult fish counts including Pacific lamprey are available on the Columbia River DART website for Prosser Diversion Dam on the Yakima River from 1983 to 2010, but adult Pacific lamprey have only been reported for 1996 and from 2002 to 2010 (Figure 4 and Table 1).[2] Pacific lamprey may have been present in other years but not reported, or were not observed. In the past decade, adult Pacific lamprey were most abundant in the Yakima River in 2003 and have declined steadily since then. Pacific lamprey numbers have declined substantially since 2004, as illustrated by the reduced numbers counted at Prosser Dam (Figure 4). Adult Pacific lamprey might pass Prosser Dam by going directly over the dam and not using the ladder where fish counting occurs; they also tend to be more active at night and if some adults passed the dam then, they are not likely to be counted. The higher numbers reported here occurred after Wydoski and Whitney's (2003) book was published.

The Yakama Peoples have a long history of harvesting Pacific lamprey in the Yakima River and many tributaries. Although this information is not readily available, it does indicate that past adult escapement into the Yakima Basin was once substantial enough to provide a sustainable, viable harvest. The low populations referenced by Wydoski and Whitney (2003) are not a natural situation but rather indicative of a population condition due to a long, sustained diminishment due to multiple factors (Yakama Nation 2011).

Wydoski and Whitney (2003) show a Pacific lamprey distributional map indicating that Pacific lamprey did not occur in the main stem Yakima River upstream from about Ellensburg, Washington (RM 160.5), and do not indicate Pacific lamprey use of the Naches River basin.

[2] http://www.cbr.washington.edu/dart/adult.html

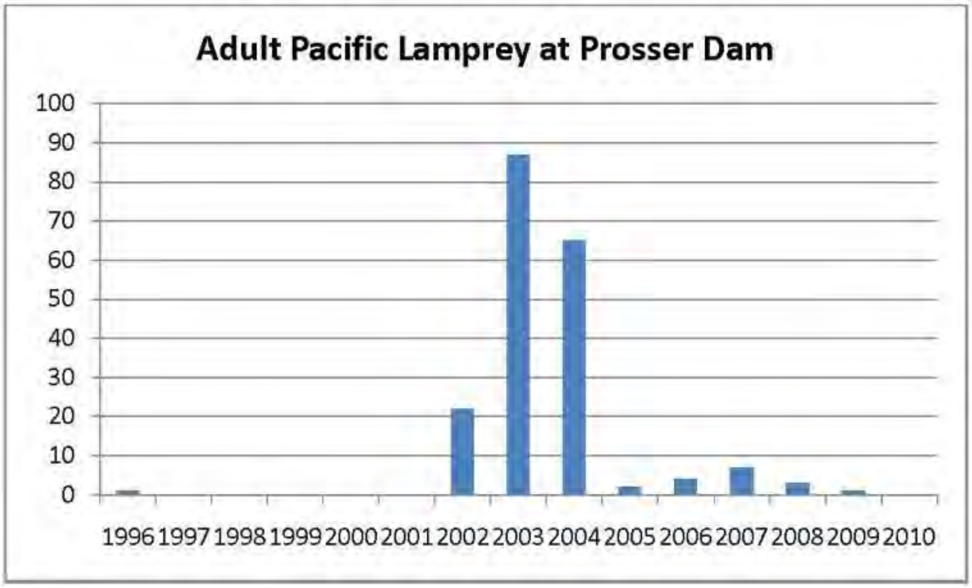

Figure 5. Count of adult Pacific lamprey at Prosser Dam from 1996 to 2010.

Table 2. Number of adult Pacific lamprey reported at Prosser Dam from 1996 to 2009. No adults were reported for 1997 to 2001.

Year	1996	2002	2003	2004	2005	2006	2007	2008	2009	2010
	1	22	87	65	2	4	7	3	1	0

Source: Columbia River DART website, accessed 24 November 2010.

Adult Pacific lamprey tend to pass Prosser Dam in the spring of the year (Figure 5), compared to the summer/fall migration timing of adult Pacific lamprey at McNary Dam (Figure 6). Only a few adult Pacific lamprey were observed in summer and fall at Prosser Dam. Adult Pacific lamprey may overwinter or hold over in the lower Yakima River or the Columbia River until the following spring before resuming upstream migration, due to some physiological or environmental cue such as water temperature. Additional information about upstream adult Pacific lamprey migration timing would be useful.

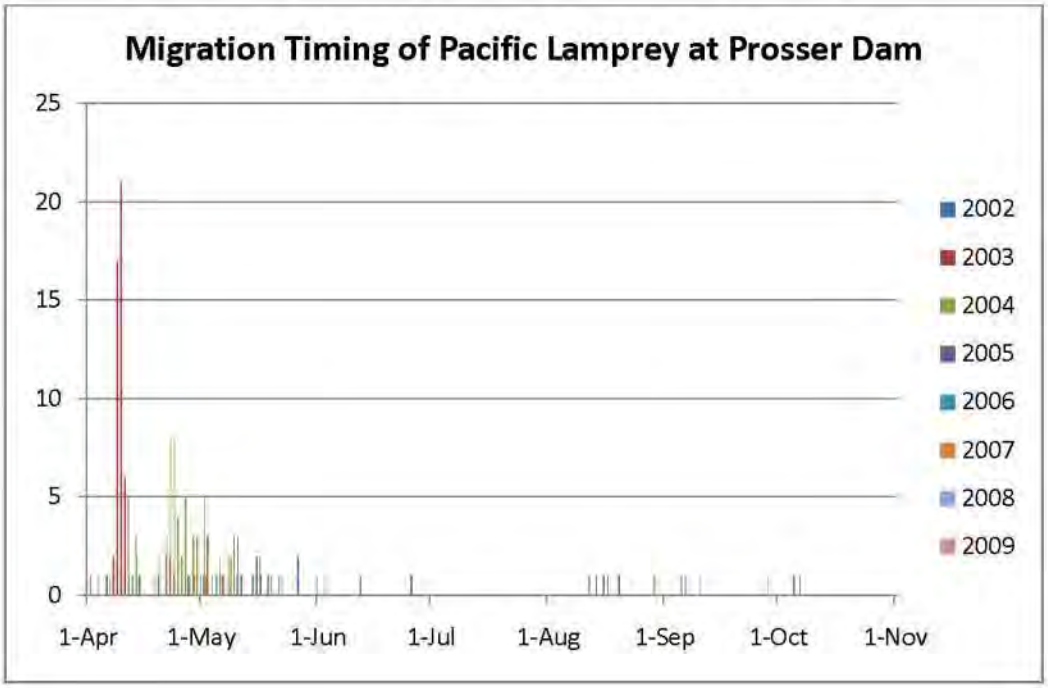

Figure 6. Migration timing of adult Pacific lamprey at Prosser Dam 2002 to 2009. Although adult numbers are low, note the predominant spring migration timing of the adult Pacific lamprey compared to the summer migration timing of adult Pacific lamprey at McNary Dam shown in Figure 6 for the same time period. Data and graph from Columbia River DART, (http://www.cbr.washington.edu/cgi-bin/dart/makegraph/dart/makegraph/html-src/adultpass.config) accessed 25 August 2010.

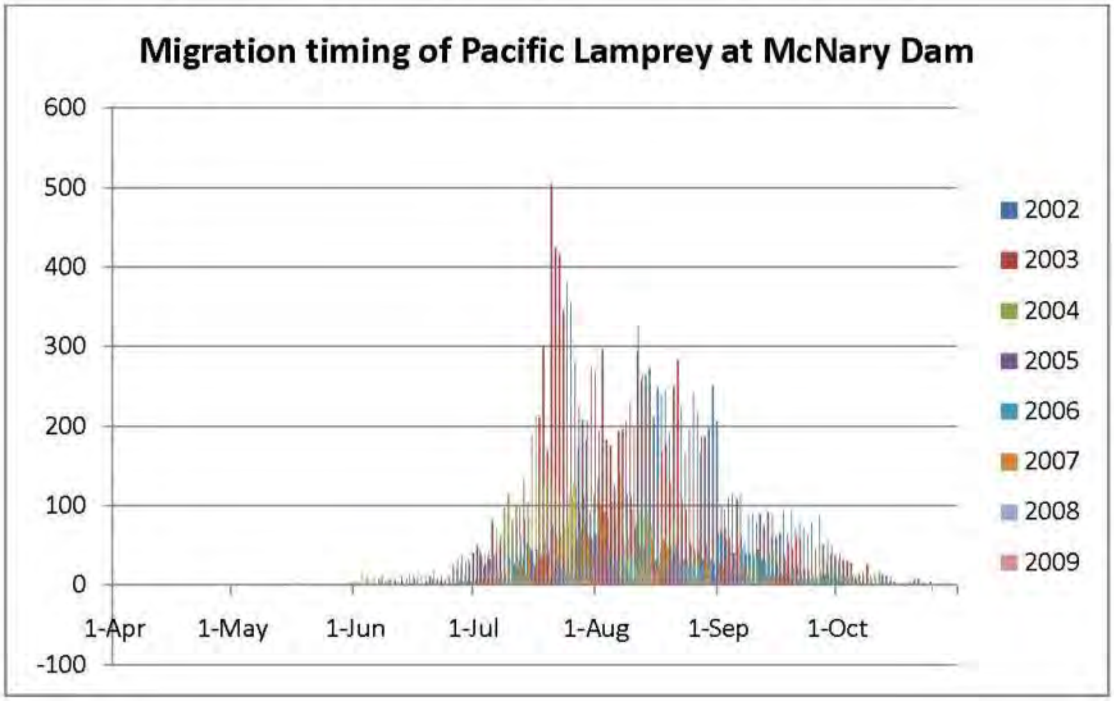

Figure 7. Migration timing of adult Pacific lamprey at McNary Dam from 2000 to 2009. Note the predominant summer-early fall migration timing compared to the springtime migration for adult Pacific lamprey at Prosser Dam shown in Figure 5. Data and graph from Columbia River DART, (http://www.cbr.washington.edu/cgi-bin/dart/makegraph/dart/makegraph/html-src/adultpass.config) accessed 25 August 2010.

The fate of adult Pacific lamprey that pass Prosser Dam is largely unknown. We are unaware of any recent information regarding adult Pacific lamprey passing Sunnyside Diversion Dam. No adult Pacific lamprey have been noted at the Roza Dam fish facility further upstream (Kline 2010), and Roza would likely be a barrier to upstream migration. At this time it is not known where Pacific lamprey spawn in the Yakima Basin, although work was initiated in 2010 by Yakama Nation biologists to survey the basin systematically to assess the presence and distribution of lamprey ammocoetes, which might also provide information on potential spawning areas and habitats.

Wydoski and Whitney (2003) do not include the Naches River as part of the historic range of Pacific lamprey in the Yakima Basin. The Naches River system has been described as “flashy” and may not provide conditions necessary to maintain populations of Pacific lamprey. In the Tieton River, a tributary to the Naches River, a combination of Rimrock Dam holding back natural sediments and scouring downstream due to operations may have reduced any naturally available habitat for either adult or juvenile life stages (Yakama Nation 2011). Surveys to evaluate potential spawning and rearing habitat for Pacific lamprey in the Naches River should be conducted, since salmon and steelhead occupy portions of the Naches River and its tributaries, and Pacific lamprey have been described as potentially occurring where salmon and steelhead occur (Simpson and Wallace 1978).

3.2.2 Juvenile Abundance

Detailed information on juvenile Pacific lamprey passing Reclamation projects in the Yakima Basin is sparse at this time. Some juvenile lamprey are observed annually during operation of the Chandler Juvenile Fish Facility. No juvenile Pacific lamprey have been observed or recorded at upstream Roza Dam.

3.3 Pacific Lamprey Abundance in the Umatilla River Basin

3.3.1 Adult Abundance

Pacific lamprey occurred historically in the Umatilla Basin. Luzier et al (2011) ranked the Umatilla basin historic occupancy extent at 250-1000 km^2 , and current occupancy extant at 4-20 km^2, indicating a decrease in range likely due to loss of habitat and/or access in tributaries of the basin. The population size is currently ranked at 250-1,000 adults in the basin, with the presence of these adults due to supplementation efforts by the CTUIR and a trend of 70% decline pre-supplementation and 10-30% decline post-supplementation (Luzier et al 2011). Adult Pacific lamprey have been documented at Three Mile Falls Dam on the Umatilla River in recent years; Table 2 shows the number of adults trapped there from 1997 to 2007.

Table 3. Adult Pacific lamprey trapped at Three Mile Falls Dam from 1997 to 2007.

Sample period	Period of capture	Number of adult lamprey
28 May – 28 Sep 2007	9 May – 7 Jun	17
5 Apr – 8 Sep 2006	10 May – 1 Jun	17
18 Apr – 29 Jul 2005	29 Apr – 6 May	6
1 Apr – 30 Jul 2004	30 Apr – 12 May	6
1 Apr – 31 Jul 2003		none
16 Aug – 30 Oct 2002		none
1 Jan 2001		none
1 Jan – 31 Jul 2000		none
16 Sep – 31 Dec 1999	16 Sep	1
7 May 1998	5 May	1
8 Jan – 28 May 1997	8 Jan – 28 May	7

The adult Pacific lamprey documented at Three Mile Falls Dam may be in part the result of the CTUIR Pacific lamprey translocation program. Information regarding adult Pacific lamprey passing Maxwell and Feed Canal Diversion Dams is not available. In addition to the adult Pacific lamprey trapped at Three Mile Falls Dam, about 20 were reported in 2010 using the LPS installed on the dam in 2009.

3.3.2 Juvenile Abundance

Detailed information on juvenile Pacific lamprey passing Reclamation projects on a downstream migration in the Umatilla Basin is sparse at this time. CTUIR biologists have sampled the Umatilla River for juvenile Pacific lamprey for several years and have compiled some information on their relative abundance and location where collected in the river (Table 4). CTUIR reported that lamprey ammocoetes have been collected during electrofishing surveys downstream from the fish screens in the Westland Irrigation District canal, and suspect that lamprey ammocoetes have been entrained into other canals as well.

Juvenile lamprey were collected by electrofishing in the Umatilla River and Meacham Creek from 1997 to 2004.[3] In the Umatilla River in August 2004, juvenile lamprey were collected from river mile (RM) 2.5 to 79.8 in a variety of substrates ranging from silt to hard packed sand and small gravel to larger gravel, cobble and boulders. In 2004, 3 sites in Meacham Creek from RM 1.5 to 10.9 were sampled in August with juvenile lamprey collected in silty and hard packed sand and small gravel substrates. Table 4 shows river location, habitat type sampled, number and average length of juvenile lamprey collected in the Umatilla River and Meacham Creek in August 2004. It appears that juvenile lamprey can use a range of substrates.

[3] http://data.umatilla.nsn.us/fisheries/lamprey/index.aspx

Table 4. Number and average length (mm) of juvenile lamprey collected by electrofishing at several sites in August 2004 in the Umatilla River and Meacham Creek. Information obtained from CTUIR website.

Habitat type	Umatilla River RM	N	Avg. length (mm)
Silty substrate	79.8	246	75.3
	69.9	95	73.3
	61.4	54	103.6
	55	5	98.8
	56.1	128	103
	50.5	3	120.7
	32.2	3	120.7
	27.1	4	93.5
	22.9	5	65
	18.2	24	76
	7.4	44	75.3
	5.8	12	58
	2.5	36	101.4
Hard packed sand and/or small gravel	74.8	79	78.7
	72.2	121	85
	70.3	27	93.1
	67	107	113.4
	48.2	3	126.7
Bedrock, large gravel, large cobble, boulders	77.6	233	83.2
	73.6	214	72.9
	71.7	139	98.2
	67.8	10	71.5
	Meacham Creek RM		
Silty substrate	1.5	62	85.5
Hard packed sand and/or small gravel	10.9	12	56.6
	3.2	122	69.5

4.0 ISSUES AND OPPORTUNITIES

4.1 Factors Affecting Pacific Lamprey

Disruption of migration corridors, both upstream adult and downstream juvenile migrations, is listed as a documented threat and reason for decline of Pacific lamprey (USFWS 2010). Factors or conditions that might limit or impede adult Pacific lamprey upstream passage include dam configuration, seasonal changes in flow, water temperature, predation by birds and other predators, or the amount of debris above, below, and on the dams. Specifically, fishway configuration at the dams may impede adult movements, and there is the potential for false attraction of adults into irrigation canal outfalls in the mainstem river. Numerous issues affecting lamprey on mainstem Columbia River dams are being explored and mitigated.

Upstream migrating adult Pacific lamprey lack the salmon's swimming stamina and are more bottom oriented since they lack a swim bladder, migrating in short bursts, then resting while attached to suitable smooth substrate with their oral disc. Physical structures such as irrigation diversion dams can be obstacles to migration due to altered flow, high velocity, sharp edges or corners on structures, etc. (Moser et al 2007). In Columbia Basin tributaries where diversions have been constructed to provide water for irrigated agriculture, many structures were constructed during a time when there was less understanding about the migration needs of anadromous fish, so little thought was given to anadromous fish passage, in particular Pacific lamprey. Some early Reclamation irrigation diversion structures were constructed in such a way that they inadvertently hindered passage of both anadromous salmonids and Pacific lamprey. Many structures have since been modified and upgraded to conform to NOAA Fisheries passage and screening criteria to accommodate Pacific salmonid migration, but these passage criteria generally do not accommodate Pacific lamprey.

Factors or conditions that might limit or impede juvenile lamprey downstream passage include seasonal changes in flow, water temperature, possible avian predation, predation by other fish species, the large amount of debris above, below, and on the dams, possible entrainment into irrigation canals, configuration and operation of the juvenile fish bypass systems if fish are diverted into the canals, etc. In addition, a potential avian predation could be a problem for both adult and juvenile Pacific lamprey.

The presence of Pacific lamprey ammocoetes in canals downstream from diversions as noted by CTUIR and Yakama Nation fisheries biologists indicates that these fish can potentially be entrained. No quantitative information exists regarding the number of Pacific lamprey ammocoetes entrained into canals, nor their fate. Many projects in the Yakima and Umatilla basins have been screened to NMFS criteria to protect outmigrating salmon, but there is concern the screens may not be effective to prevent entrainment of juvenile lamprey and may also result in impingement mortality on the structures. The extent and mechanism by which juvenile lamprey are entrained is uncertain, but it appears they may become impinged on flat screens and harmed by the cleaning mechanisms, or attach to the surface of drum screens and be carried up and over the screen structure into the canal with the rotation of the drum.

Environmental conditions may vary annually in the basin, based on conditions such as snowpack and associated runoff and project operation, which could affect both upstream and downstream passage opportunities for adult and juvenile lamprey.

As in most cases regarding adult fish passage, information about average flows during the time of year that adult Pacific lamprey migrate would be needed. Flow adjustments might be one approach to accommodate upstream migrating Pacific lamprey adults.

4.2 Opportunities for Addressing Issues

Adult Pacific LPS's are structures designed to provide upstream migrating adult Pacific lamprey with an easier and more benign passage route around dams compared to traditional fish ladders designed for adult Pacific salmonids. LPSs are relatively simple structures and allow adult Pacific lamprey to avoid the mostly unfavorable and high velocity passage conditions in fish ladders designed for adult salmonids. The basic design of the LPS is a smooth metal trough a few inches deep and 24 or more inches wide that provides a low flow of low velocity water. The smooth surface allows the adult Pacific lamprey to attach to the structure with their oral disc and rest before making another upstream run against the current. LPSs have been developed, installed, and tested at lower Columbia River hydropower projects (Moser et al. 2008, 2010), and based on the positive results from these tests, LPSs have been designed and installed at several additional structures in the Columbia River basin, including Three Mile Falls Dam and Feed Canal Diversion Dam, both on the Umatilla River. A simple flat plate was installed at Maxwell Diversion Dam in 2010.

The US Army Corps of Engineers, through a "Planning Assistance to the States Grant" with the Yakama Nation has contracted with the U.S. Fish and Wildlife Service, Mid-Columbia Fisheries Resource Office, Leavenworth, Washington, to radio-tag and track adult Pacific lamprey in the lower Yakima River beginning in 2011, and to expand the study as necessary as information is acquired and future funding becomes available. Reclamation has provided some funding for this study. This radio-tracking study is expected to provide information on whether and where adult Pacific lamprey approach and pass lower Yakima River water diversion projects, and the results from the study would inform any decision as where to locate an entrance to a LPS to provide the best conditions and opportunities for successful upstream adult Pacific lamprey passage.

Design of LPSs would have to be site-specific, based on conditions at the project and configuration of the project, the area in the river where the adult Pacific lamprey approach the project, and on successful designs that have been developed and tested in the lower Columbia River. A design for a LPS would have to consider the approach route of Pacific lamprey to the structure, most likely informed by radio telemetry studies. Approach characteristics and hydraulic conditions to attract adult Pacific lamprey to the LPS need to be investigated and criteria developed, although the approach characteristics of existing LPSs should provide initial guidance for design and placement. The LPS can have an angle of up to 45 degrees (Simonson 2010). If the run is long, that is, if a long ramp is needed to move the adults over a high vertical distance, then rest areas need to be provided. The spacing of rest areas, if needed, can be estimated from designs of LPSs at lower Columbia River hydropower projects where high vertical distances needed to be overcome. The location and configuration of the exit at the upstream end of the LPS will require some thought and consideration regarding the biological needs of the fish and engineering considerations, based on the configuration of each project, and seasonal water level fluctuations.

Many projects in the Yakima and Umatilla basins have been screened to NMFS criteria to protect outmigrating salmon, but the extent of juvenile entrainment or impingement on screen facilities installed and operated for salmon is not known. The USGS Columbia River Research Laboratory, Cook, Washington, is conducting some lamprey work in progress that is expected to provide additional information about passage and entrainment protection criteria for Pacific lamprey. Reclamation is also investigating various methods to guide migrating juvenile lamprey away from diversions.

5.0 YAKIMA RIVER BASIN PROJECTS

The Bureau of Reclamation's Yakima Project provides irrigation water for a narrow strip of fertile land that extends for 175 miles along the Yakima River in south-central Washington (Figure 8). The Yakima River flows southeasterly for about 215 miles from its headwaters in the Cascades to its confluence with the Columbia River. The Naches River is its largest tributary. The basin drains about 6,150 square miles, or 4 million acres. Reclamation operates the project to provide irrigation water, instream flows for fish, and flood control. The irrigable lands total about 465,000 acres. There are seven divisions in the project. Reservoir storage constitutes one division. Storage reservoirs in the upper basin include Keechelus, Kachess, Cle Elum, Tieton, Clear Creek, and Bumping Lake. In addition, there are six water delivery divisions: Kittitas (59,123 acres); Tieton (27,271 acres); Sunnyside (103,562 acres); Roza (72,511 acres); Kennewick (19,171acres); and Wapato (136,000 acres), operated by the Bureau of Indian Affairs (BIA) for irrigation on Yakama Nation lands. Other project features include 5 diversion dams, 420 miles of canals, 1,697 miles of laterals, 30 pumping plants, 144 miles of drains, 9 power plants, plus fish passage and protection facilities throughout the project. There are also numerous non-Reclamation diversions for irrigation and other uses in the Yakima Basin. Additional information regarding all the Yakima Project facilities and operations is provided in the Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington (Reclamation 2002).

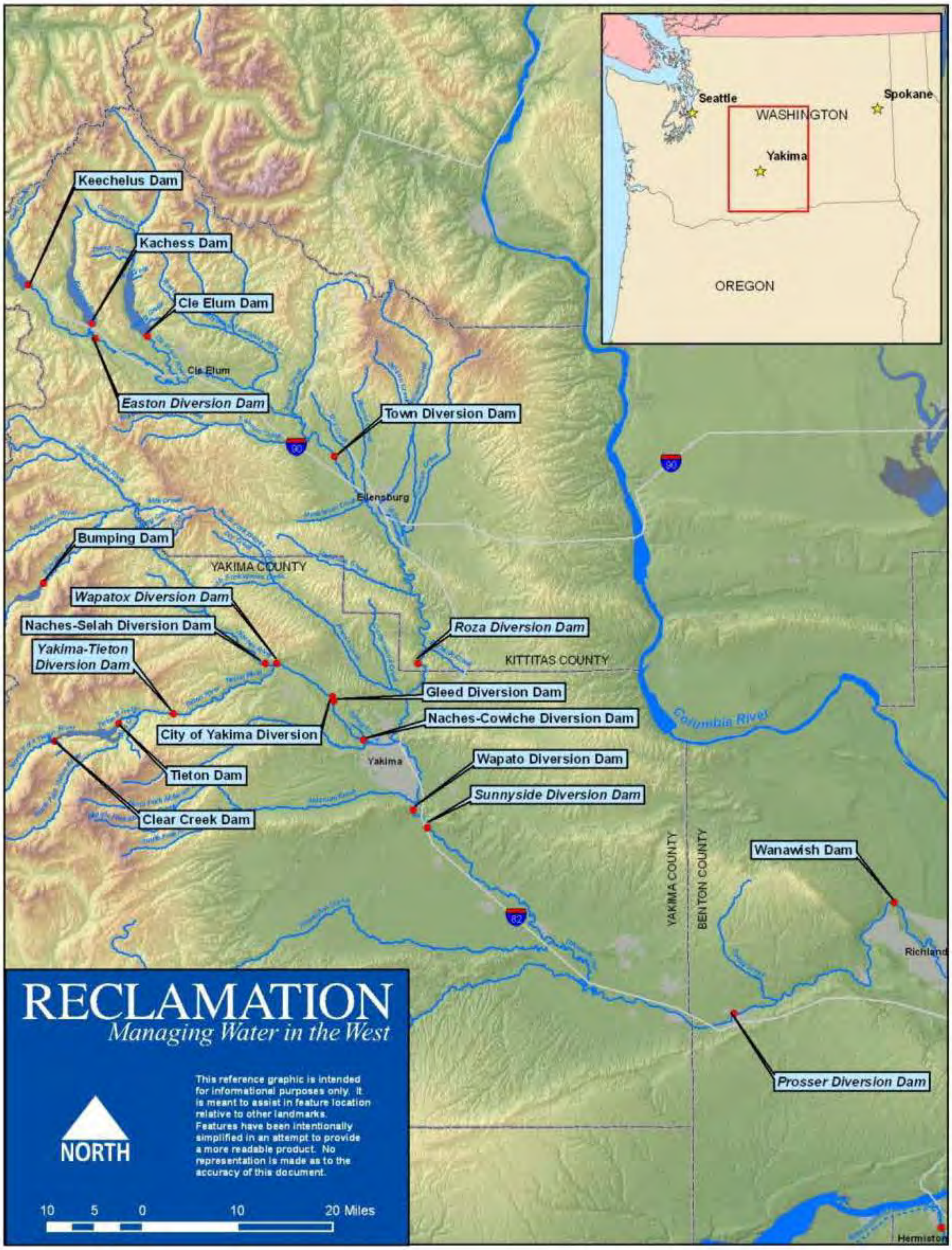

Figure 8. Map of the Yakima River basin.

An operational scheme called flip-flop was initiated in 1981 to encourage spring Chinook salmon to spawn at lower flow levels in the upper Yakima River above the mouth of the Teanaway River, so that the flows required to keep the redds watered and protected during the subsequent incubation period (November through March) are minimized from upper Yakima reservoir storage. For the flip-flop operation, project operations drafts heavily from Keechelus, and sometimes Kachess, and Cle Elum Lakes on the Yakima arm to meet lower basin irrigation demands during the summer (July and August) and maintains storage in Rimrock Lake on the Naches River arm to meet lower basin demands later in the year (August 25th through October 20th). Flip-flop operation reduces flows in the upper Yakima River during the latter portion of the irrigation season. The flow reduction process in the upper Yakima River starts September 1st and is ramped down over a 10-day period. With this reduction of flow in the upper Yakima Basin during the fall (September and October), most lower basin demands are then met with Rimrock Lake storage releases of up to 2,400 cfs to the Naches River Arm. It is unknown how the flip-flop operational scheme would affect upstream migrating Pacific lamprey in the upper Yakima basin, although flows in the lower river would be expected to remain stable within the framework of annual variation and demand.

Water diversion projects in the Yakima Basin are described in two sections, Reclamation or non-Reclamation. In each section they are discussed from downstream to upstream, the order in which upstream migrating adult Pacific lamprey would encounter the projects. Mainstem Yakima River (4th-field HUC 17030003 and HUC 17030001) projects are considered first, then the projects on the Naches River and its tributaries (4th-field HUC 17030002). Table 5 (List of Projects - Summary Table is located in Appendix A) provides an overview of major Yakima Basin irrigation diversion and storage facilities; detailed discussion follows below. The discussion will include information regarding the presence/absence of Pacific lamprey, conditions potentially affecting them, as well as recommendations for further study or projects that could be implemented to address Pacific lamprey issues.

5.1 Reclamation Diversion Facilities

At this time there are no structures or features specifically designed to provide or enhance adult Pacific lamprey upstream passage at Reclamation water diversion projects in the lower Yakima River basin. Adult Pacific lamprey must utilize either the existing adult salmonid passage facilities or find some other route around the projects.

5.1.1 Prosser Dam

Prosser Dam was constructed in 1904 at RM 47.1 of the Yakima River and modified by Reclamation in 1932-33 and 1956. Reclamation owns and operates the dam and fish passage facilities. The left bank diversion diverts a maximum of 1,500 cfs of water into the Chandler

Power Canal for irrigation of about 7,698 acres in the Kennewick Irrigation District and for power production at the Chandler Power Plant. A total of 12 MW are generated downstream at the power plant, but generation varies seasonally (Reclamation 2002). The dam has left bank, center, and right bank fish ladders, designed primarily to provide passage for upstream migrating adult salmon and steelhead.

Figure 9. Prosser Dam.

Adult Pacific lamprey have been documented at Prosser Dam, but their fate (both survival and spawning success) above the dam is unknown. It is not known if adult Pacific lamprey pass Prosser dam by routes other than the existing fish ladders. Prosser Diversion Dam may be a partial barrier to upstream passage of adult Pacific lamprey, in the sense that the existing fish ladders were designed to pass adult salmonids upstream. A LPS could be installed on the dam to enhance adult passage if it is determined that the dam is a partial barrier to upstream adult Pacific lamprey passage, but additional information is needed to determine if it is necessary, practical and feasible. Radiotelemetry studies that are expected to begin in 2011 should provide some information regarding the migration route and approach of adult Pacific lamprey to the dam. This facility could be a source to capture migrating adult lamprey for the radiotelemetry study, and/or provide a location to hold and overwinter adults captured in the summer to be released for the radiotelemetry study at a later time.

The juvenile fish bypass system screens at Prosser dam are designed for diverting juvenile salmonids back to the river and consist of rotating drum screens with 4-12 stainless steel screen, which has an approximately 5/32 inch opening. NMFS screening criterion for fry specifies a 3/32 inch woven wire mesh (NMFS 1997), and the new replacement 4½-12 woven wire mesh, approximately 1/8 inch, is expected to be an interim step to achieving this criterion (Leonard and Kline 2010). Actively downstream migrating juvenile Pacific lamprey (macropthalmia) moving into the canals would likely be diverted by the rotating drum fish screens to the fish bypass and then back to the river, since these migrating Pacific lamprey juveniles are relatively large. However, passage back to the river of downstream migrating macropthalmia has not been evaluated and it is not known what proportion may be ineffectively screened or harmed by the screen mechanism. It is also necessary to determine whether the existing 0.5 feet per second approach velocity criterion at the Phase I (larger and older) sites is sufficient to reduce the likelihood of juvenile Pacific lamprey being entrained or impinged on the screens. Larger ammocoetes or macropthalmia would most likely be guided to a fish bypass than would the younger and smaller one- or two-year-old ammocoetes, since the larger and older juveniles are relatively stronger swimmers. Surveys behind the screens would indicate the entrainment of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

5.1.2 Sunnyside Dam

Sunnyside Dam was constructed in 1907 at RM 103.8 of the Yakima River. The left bank diversion diverts a maximum of 1,300 cfs of water into the Sunnyside Canal for irrigation of about 80,764 acres. Canal flow varies from 600 to 1,300 cfs during the irrigation season (mid-March through October 20). Reclamation owns Sunnyside Dam; it is operated and maintained by Sunnyside Valley Irrigation District (SVID). Fish passage facilities are operated and maintained by Reclamation. Similar to Prosser Dam, Sunnyside Dam has three fish ladders, left bank, center, and right bank designed to provide passage for upstream migrating salmon and steelhead. At this time there are no structures or features specifically designed to provide or enhance adult Pacific lamprey upstream passage at Reclamation water diversion projects in the lower Yakima River basin. Adult Pacific lamprey must utilize either the existing adult salmonid passage facilities or find some other route around the project. Flow in the lower Yakima River is monitored and controlled at Sunnyside Dam.

Figure 10. Sunnyside Diversion Dam.

There are no adult fish counts at Sunnyside Diversion Dam, so it is unknown if adult Pacific lamprey pass this facility, or even if those adults that successfully pass Prosser Dam make it as far upstream as Sunnyside Dam. Additional information is needed to determine if it is necessary, practical and feasible to install an LPS at this facility. As part of the proposed radiotelemetry study, receivers could be located in a manner to provide information regarding the migration route and timing of adult lamprey at Sunnyside.

The juvenile fish bypass system screens at Sunnyside and Prosser dams are designed for diverting juvenile salmonids back to the river and consist of rotating drum screens with stainless steel woven wire mesh with an approximately 1/8-inch opening. NMFS screening criterion for fry specifies a 3/32-inch woven wire mesh (NMFS 1997), and this is an interim step to achieving this criterion (Leonard and Kline 2010). Actively downstream migrating juvenile Pacific lamprey (macropthalmia) moving into the canals would likely be diverted by the rotating drum fish screens to the fish bypass and then back to the river, since these migrating Pacific lamprey juveniles are relatively large. However, passage back to the river of downstream migrating macropthalmia has not been evaluated and it is not known what proportion may be ineffectively screened or harmed by the screen mechanism. It is also necessary to determine whether the existing 0.5 fps approach velocity criterion at the Phase I (larger and older) sites is sufficient to reduce the likelihood of juvenile Pacific lamprey being entrained or impinged on the screens. Larger ammocoetes or macropthalmia would most likely be guided to a fish bypass than would the younger and smaller one- or two-year-old ammocoetes, since the larger and older juveniles are relatively stronger swimmers. Juvenile lamprey have been observed behind the screens at Sunnyside, although it is not known if they were Pacific lamprey or the Western brook lamprey (*Lampetra richardsoni*), a freshwater lamprey that closely resembles the Pacific lamprey at the ammocoete stage (Luke 2010). This information indicates the possible entrainment of juvenile lamprey; further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

5.1.3 Roza Dam

Roza Dam in Yakima River 4th-field HUC 17030001 was completed in 1939 at RM 127.9 on the Yakima River about 12 miles north of Yakima, Washington. The dam is a concrete weir, movable crest structure, 486 feet long at the crest, and 67 feet high with a variable water surface elevation (N.W.S. 1220.60 feet) controlled by two 110-foot by 14-foot motor operated (float controlled) roller gates. This irrigation and hydroelectric power diversion dam provides water diversion of up to 2,200 cfs to the Roza main canal, of which up to 1,350 cfs design capacity (actual diversion 1,260 cfs) is delivered to RID during the irrigation season (mid-March through October 20th). Maximum diversion into the canal occurs from May through September in most years. The canal is usually empty for several weeks during late October and/or November for canal and fish passage maintenance.

Reclamation owns and operates all the facilities at Roza Diversion Dam except for the adult fish trapping facility that is operated by the Yakama Nation. Roza Dam has fish ladders on both sides. The main fish ladder is a concrete structure in the left abutment. An auxiliary ladder is located in the right abutment and is connected by a gallery to the main fish ladder. Operation of the fish ladder, including the auxiliary water supply, requires a minimum flow of about 120 cfs to remain within criteria. The right bank fish ladder has four weirs that guide fish into the gallery and which provides access to the left bank ladder for fish passage up and over the dam. At the top of the left bank fish ladder, fish move up and into the adult fish trapping facility operated by the Yakama Nation.

No adult Pacific lamprey have been observed at the fish facility at Roza Dam. As currently configured, Roza Diversion Dam may be a barrier to upstream passage of adult Pacific lamprey, in the sense that the existing fish ladders were designed to pass adult salmonids upstream. A LPS could be installed on the dam if deemed necessary to pass adult Pacific lamprey upstream. A LPS at Roza Dam would likely be a complicated structure because of the existing features and physical configuration of the dam.

Radio tagging and tracking of adult Pacific lamprey would be necessary to determine their approach route up to the dam to determine where to site a LPS entrance. A LPS on the left bank would probably need to have the entrance sited downstream from the turbulence at the mouth of the existing fish ladder, and would have to wind around various sections of dam infrastructure to get the adult Pacific lamprey up to the top of the dam, and connected to the last pool of the left bank fish ladder or into the forebay. Adult Pacific lamprey would probably then go to the adult fish trapping facility for counting and collection of biological data by tribal biologists.

Operation of the roller gates could affect outmigrating juvenile Pacific lamprey. When roller gates are operated in a "tucked" position, there is surface flow over the submerged gate and juvenile lamprey could outmigrate with this flow. In the "untucked" or "on seal" normal operation, however, water flows through the gates below the surface and lamprey would have to sound to find the discharge and may be delayed. However, juveniles may be able to pass under the roller gates if the migrate near the bottom. Outmigrating juveniles may also be diverted into the canal, and if screens are sized properly to screen outmigrants, they would be bypassed back to the river. Surveys behind the screens would indicate the entrainment of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

5.1.4 Easton Diversion Dam

Easton Diversion Dam is owned and operated by Reclamation. It was completed in 1929 on the Yakima River at RM 202.5 near Easton, Washington. It is a concrete gravity ogee weir, movable crest structure. This dam is 66 feet high. An irrigation diversion check structure with the Kittitas main canal headworks (capacity 1,320 cfs) located in the right abutment is operated and maintained by Kittias Reclamation District.

This dam has a vertical slot fish ladder on the left side designed to allow passage of adult salmon, principally spring Chinook salmon (*Oncorhynchus tshawytscha*), upstream to suitable spawning areas. Adult steelhead apparently do not use the ladder; their numbers are fairly low in the Yakima Basin in general, and particularly low in the upper basin. Lamprey may be able to use this ladder if configuration allows. This dam has no separate spillway like the upper Yakima River water storage projects that will be discussed below. The diversion is screened for downstream migrating juvenile salmonids and any juvenile salmonids screened are returned to the river through a bypass pipe that enters the river just downstream from the dam. Irrigation diversion is provided from April 20th through October 15th. Yakima Project operations coordinates closely with KRD to accomplish a variety of operational needs including irrigation, fisheries, flood control, recreation, and maintenance to structures.

Wydoski and Whitney (2003) show Pacific lamprey distributed in the Yakima River up to about the location of Ellensburg, Washington (RM 160.5). Easton Diversion Dam at RM 202.5 is about 42 miles upstream from Ellensburg. The possibility that Pacific lamprey occurred in the river above Ellensburg cannot be ruled out, but available information suggests that they did not. A U.S. Forest Service review of fish distribution databases for the upper Yakima Basin found no references to Pacific lamprey occurring there (Mayo 2010).

If deemed necessary to provide adult Pacific lamprey passage at this structure at some time in the future, it is possible that an adult Pacific lamprey LPS could be installed to move adult Pacific lamprey up and over the dam into the river above. The amount of suitable Pacific lamprey spawning habitat upstream is unknown, especially since the major tributaries have large water storage projects constructed on them. If suitable spawning habitat exists and if reproduction and rearing were successful, Pacific lamprey macropthalmia could probably move downstream in the flow over the dam. If juveniles were diverted into the canal, they would likely be screened and returned back to the river through the juvenile salmonid bypass system. If Pacific lamprey are found to occur this far up in the river, surveys could be done to determine the entrainment of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment, if warranted.

5.1.5 Wapatox Diversion Dam

Wapatox Diversion Dam is on the Naches River at RM 17.1 upstream from Yakima, Washington. Reclamation owns and operates this facility, purchased in 2003. The power plant has been decommissioned but diversions of about 130 cfs continue to provide about 50 cfs for irrigation. Diversions greater than the actual amount needed for irrigation are required since the lateral entrances are high and were originally designed to operate at a higher flow of about 300 cfs. The diversion dam has a 2-pool fish ladder on the left side, but the dam is low enough that migrating adult salmon and steelhead could potentially jump the dam itself. It is unknown where adult Pacific lamprey would approach the dam.

An adult Pacific lamprey LPS could likely be installed at Wapatox Dam, if passage were deemed necessary and appropriate to get adult Pacific lamprey upstream. Radio tagging and tracking of adult Pacific lamprey would be necessary to determine their approach route to the dam and the best place to site a LPS entrance.

Wapatox fish screens consist of two vertically-oriented flat-plate wedge-wire screens built by Pacific Power and Light and bought by Reclamation in March 2003. These screens are oriented in a V-shape which directs fish to a single fish bypass situated at the downstream end of both at the pinnacle of the ‘V’. Both screens are cleaned with an automatic brush system and were designed for about 400 cfs, though have a maximum diversion of 140 cfs now that the power plant has been dismantled and the canal is only used for irrigation water delivery.

Downstream migrating juvenile Pacific lamprey would likely move down over the dam, or if entrained into the canal should be returned to the river through the fish bypass system to some degree. However, passage back to the river of downstream migrating macropthalmia has not been evaluated and it is not known what proportion may be ineffectively screened or harmed by the screen mechanism. Juvenile lamprey have been observed behind the screens at Wapatox, although it is not known if they were Pacific lamprey or the Western brook lamprey (*Lampetra richardsoni*), a freshwater lamprey that closely resembles the Pacific lamprey at the ammocoete stage (Luke 2010). This information indicates the possible entrainment of juvenile lamprey; further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

5.1.6 Yakima-Tieton Diversion Dam

Yakima-Tieton Diversion Dam is located at RM 14.2 on the Tieton River. The dam and associated structures and the fish ladder and screens are owned and operated by Reclamation. This diversion provides water for the Yakima-Tieton Irrigation District (YTID) during the irrigation season (mid-March through mid-October). The diversion has a designed diversion capacity of 320 cfs, but can pass up to 350 cfs. A new flat plate fish screen was installed in 1996, 1,000 feet down the YTID main canal with a fish return pipe to the right side of the Tieton River.

It appears that it would be relatively easy to install a LPS at this site if it was determined that such a structure would aid adult Pacific lamprey upstream passage. Juvenile Pacific lamprey migrating downstream could go over the dam, or if they did enter the canal, they could be screened from the diverted flow and returned to the river through the fish bypass system. The screens are constructed of 3/32-inch wedge-wire screen to NOAA Fisheries criteria for fry.

If juvenile lamprey become impinged on this type of screen, they could be harmed by the cleaning mechanism. Evaluation of juvenile lamprey survival on these screens is not known, and is a need for further study. Surveys behind the screens would indicate the entrainment of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

5.2 Non Reclamation Diversion Facilities

5.2.1 Horn Rapids (Wanawish) Dam

Horn Rapids Dam, also known as Wanawish Dam, at RM 18, is owned by Columbia Irrigation District. It is the first structure or barrier that upstream migrating adult Pacific lamprey encounter in the Yakima River. Reclamation constructed and oversees maintenance of the left and right bank fish ladders. The ladders were constructed in the late 1980s-early 1990s, and a new dam crest was constructed in 1996. This dam does not appear to be an obstacle to upstream adult salmon passage; they appear to jump the dam and typically do not use the ladders. The fish ladders are of a vertical slot design. The right bank fish ladder generally is not operated. The left bank fish ladder is typically open to adult fish passage but is sometimes out of criteria with regard to attraction flow.

The left bank diversion at Horn Rapids Dam supplies the Richland Canal, while the right bank diversion supplies the Columbia Irrigation District canal. The diversions divert about 100 cfs. The diversion structures and fish ladders are possible sites for placement of radio telemetry equipment and potential locations for LPSs. This is also a potential location to trap adults for the radiotelemetry study.

Figure 11. Horn Rapids (Wanawish) Dam.

Adult Pacific lamprey have been documented at Prosser Dam, so at least some adult Pacific lamprey successfully pass Horn Rapids Dam, although it might still be an impediment or partial barrier to upstream migration. Radio telemetry or other studies might help determine whether Horn Rapids Dam as currently configured is a partial barrier to upstream adult Pacific lamprey migration. Adult Pacific lamprey may be able to negotiate the face of Horn Rapids Dam, depending on the configuration of the downstream face of the dam, that is, whether the base of the dam is continuous with the river bed, or if is it undercut and not easily negotiated by migrating adult Pacific lamprey. An LPS might not be needed at Horn Rapids Dam if the adults can readily negotiate the dam in its present configuration or a LPS could be something as simple as a properly located flat plate.

A potential avian predation problem for both adult and juvenile Pacific lamprey exists at Horn Rapids Dam; numerous white pelicans were observed holding in the roll just below the dam on the 5 May 2010 site visit, and many more were on a small gravel bar just downstream from the dam.

The left side Richland Canal has rotating drum fish screens downstream from the diversion. These screens are not designed to meet all of the most recent NOAA Fisheries juvenile salmonid criteria. The rotating drum screens are fully automated and constructed of 4.5-12 steel mesh, and operated at 70 percent submergence. The screen has an open area of about 28 percent; new replacement screens when needed will be fabricated from 6-14 steel screen, and have 27 percent open area. The ladder and screens on the CID canal are similar. The existing fish screens might be adequate to guide juvenile Pacific lamprey back to the river, but more information about behavior of juvenile lamprey as they approach and react to the screen may be warranted.

5.2.2 Wapato Diversion Dam

Wapato Diversion Dam at RM 106.6 on the Yakima River is owned and operated by the Bureau of Indian Affairs' Wapato Irrigation Project and diverts about 2000 cfs of irrigation water from the right bank diversion. This dam consists of an east branch and a west branch. The irrigation diversion is on the west branch. Both branches have adult fish ladders similar to those at Sunnyside Diversion Dam. The juvenile fish screen structure on the canal is relatively large compared to those at other projects, to accommodate the larger flow diverted at Wapato Dam. If studies determine that adult Pacific lamprey migrate upstream to Wapato Diversion Dam, and if it is deemed appropriate to install a LPS to provide adult lamprey passage there, the Pacific lamprey adult radio telemetry studies could inform any decision regarding where to locate an adult LPS. Juvenile Pacific lamprey could move downstream over the dam or through the fish screen structure.

Figure 12. Wapato Dam.

5.2.3 Town Diversion Dam

Town Diversion Dam located at RM 161.3 on the Yakima River is owned and operated by the Town Ditch Company. Town Diversion Dam is a low head mainstem diversion dam that might not be a serious impediment to passage of adult Pacific lamprey. This low head (hydraulic height 3.35 feet) mainstem diversion dam provides water to about 12,000 acres in the Ellensburg Valley during the irrigation season (mid-April through mid-October), and also provides supplemental water to the City of Ellensburg through a supply pipe about 300 feet downstream of the headworks. From April through October a maximum of +/- 230 cfs is diverted for irrigation and fish screen operations. From November through March, water may be diverted for stock watering and/or city M&I water. This low-head dam might not be a serious impediment to passage of adult Pacific lamprey. Reclamation operates and maintains the fish ladder on the right side of the dam and the fish screens on the left side of the dam. The ladder is a notched weir structure with submerged orifices. If a LPS is deemed necessary for adult Pacific lamprey passage at this site, it would not have to be an elaborate structure and could be as simple as a flat plate.

Radio tagging and tracking of adult Pacific lamprey would be necessary to determine preferred approach routes to the dam for siting a LPS entrance or a flat plate. Adult Pacific lamprey might be able to move upstream through the fish ladder, depending on water velocity in the ladder. Outmigrating juvenile Pacific lamprey should be able to move downstream in the flow over the dam. This diversion dam is near Ellensburg, Washington, which is about the upstream extent of the distribution of Pacific lamprey in the Yakima River, as noted by Wydoski and Whitney (2003). If this is indeed the historic upstream extent of the distribution of Pacific lamprey in the Yakima Basin, there may be some ecological reasons that Pacific lamprey apparently did not occur in the river upstream.

5.2.4 Naches-Cowiche Diversion Dam

Naches-Cowiche Diversion Dam is located at RM 3.6 on the Naches River near Yakima, WA. Water is diverted at this dam for the City of Yakima and the Naches-Cowiche Irrigation District, which provides water principally for residential use. Diversions total about 40 cfs, although a diversion consolidation in progress would increase this amount to about 75 cfs. The adult salmon fish ladder on the left side of the dam is essentially nonfunctional given the high flows in the river that deposit large quantities of gravel near the outlet of the ladder and gravel deposits downstream from the ladder limit fish access to the entrance of the ladder. Fish exiting the ladder would encounter thin water and much gravel. The dam is low enough that during the adult Chinook salmon upstream migration, they can apparently ascend the dam relatively easily.

Upstream migrating adult Pacific lamprey might be able to pass the dam. At the time of the survey (12 August 2010), river flow was low. It is not known exactly when adult Pacific lamprey would pass this dam, since there are no data that suggest that Pacific lamprey used the Naches River historically, but it could provide quality habitat if lamprey were re-established in the Yakima Basin. Based on the limited data on upstream migration timing of adult Pacific lamprey at Prosser Dam shown above in Figure 5, adults might reach the Naches-Cowiche Diversion Dam in late spring-early summer. The concrete on the face of the dam appears to be coarse and rough, and the potential installation of a flat plate or steel plates conforming to the shape of the dam could provide a smooth surface for adult Pacific lamprey migrating upstream. The appropriate passage structure may depend on timing. A LPS might be appropriate for this dam, since higher flows would be expected at the dam earlier in the year if migration timing at Prosser Dam is indicative of estimated migration timing at Naches-Cowiche, with timing lagged by swimming speed of adult Pacific lamprey. But if adults migrate upstream later in the year at lower flows, some smooth surface on the dam might be all that is necessary to provide passage. Juvenile lamprey outmigration in the spring is expected to be unimpeded due to high flows in the river and the wide expanse of the dam. Water diversions start about 1 April at this facility and the rotating drum screens are fitted with 3/32-inch perforated plate, and small amounts of water are diverted compared to the flow in the river.

5.2.5 Gleed Diversion Dam

Reclamation staff did not visit this structure at Naches River RM 9.4. It is described, however, as being similar in configuration and operation as the upstream Naches-Selah Diversion Dam and fish screen described below. There is what amounts to a push up dam to direct lower river flows to the diversion later in the season, but it does not block the entire river, so upstream migrating adult Pacific lamprey should be able to move relatively easily along river right. Downstream migrating juvenile Pacific lamprey should be able to move freely past the facility.

5.2.6 Naches-Selah Diversion Dam

Naches-Selah Diversion Dam is on the Naches River at RM 18.4. Diversion of water at this facility is maintained late in the summer by what amounts to a push-up dam in the Naches River. This directs much of the river flow into the canal. This is needed in late summer when the flow in the Naches River drops to about 250 cfs. The water right at this facility is for about 120 cfs, but more water is diverted than is needed and the excess then returned to the river before it reaches the screens and the canal proper. Adult upstream migration of Pacific lamprey should not be an issue here, since there is no large obstruction in the river to impede their movement. Depending on Pacific lamprey migration timing, the adults might make it up this far in the river before the push-up dam is needed. If adults were to spawn successfully upstream from here, outmigrating juveniles in the spring would most likely go down the river and pass this diversion. If, however, water was being diverted, some juveniles would likely be returned to the river through the excess water return structure prior to encountering the fish screens. Adult upstream migration would not be expected to be a problem at high flows, but low flows in the fall (September- October) would be a concern for upstream migrating adult spring Chinook salmon and steelhead. In spring, river flows are generally adequate, so the facility should not be an impediment to downstream passage of juveniles. Diversions at this facility start 1 April. The wedge-wire screen complies with NMFS screening criteria.

5.3 Reclamation Storage Facilities

Reclamation owns and operates three major water storage projects in the upper Yakima Basin: Cle Elum, Kachess and Keechelus dams; Bumping Lake Dam on a tributary of the Naches River, and Tieton and Clear Creek dams on the Tieton River. These projects are high up in the system and most are enlarged natural glacial lakes. It is unknown if Pacific lamprey historically occupied areas or tributaries upstream from these high elevation dams. Wydoski and Whitney (2003) do not show Pacific lamprey distribution above about Ellensburg in the mainstem Yakima River and none in the Naches River, and a U.S. Forest Service review of fish distribution databases for the upper Yakima Basin found no references to Pacific lamprey occurring there (Mayo 2010). However, these areas could provide lamprey habitat and the lack of distribution data is likely due to the extremely low population of lamprey in the Yakima Basin.

Though not well understood, the operations of these storage facilities may potentially affect downstream lamprey habitat due to interruption of sediment transport and operational effects on water temperatures. These facilities may also affect river water elevations resulting in potential dessication of juvenile lamprey due to operations and ramping rates. Further investigation into these possible effects is warranted if lamprey restoration efforts indicate the potential for lamprey to use habitat in the areas affected by these operations.

We also provide here a discussion of Reclamation water storage projects to provide a comprehensive assessment of potential adult and juvenile Pacific lamprey passage concerns. Except for Clear Creek Dam, these upper basin water storage projects do not have adult fish passage facilities. Fish passage facilities at Clear Creek Dam are located on the spillway and were installed to provide bull trout in Rimrock Lake access to potential spawning and rearing tributaries upstream from Clear Creek Dam. Passage for anadromous salmonids is proposed for Cle Elum Dam and Bumping Lake Dam to allow access to their historic range and spawning and rearing habitat (Reclamation 2003). Reclamation estimated the amount of suitable spawning and rearing habitat that would be available to anadromous salmonids upstream from five of the upper basin projects (Reclamation 2003); it is unknown if this habitat would be suitable for Pacific lamprey spawning and rearing.

5.3.1 Cle Elum Dam

Cle Elum Dam is located on the Cle Elum River at RM 8.2. Cle Elum Dam as currently configured would be a barrier to upstream migration of adult Pacific lamprey as well as anadromous salmonids. The proposed new adult anadromous salmonid trap and haul passage system may provide an opportunity to move adult Pacific lamprey above the dam to seek out suitable spawning habitat in upstream tributaries. The Phase I report (Reclamation 2003) indicated that about 29 miles of suitable salmonid spawning habitat would be available if access were provided (Reclamation 2003), and some of this habitat might be suitable for Pacific lamprey. If adult Pacific lamprey successfully moved through the reservoir and located tributaries, and if spawning and rearing were successful, outmigrating macropthalmia would need to travel the length of the reservoir and seek out the proposed juvenile salmonid downstream passage structure. Without the new juvenile downstream passage structure, outmigrating juvenile lamprey could only exit the reservoir when water is at or above spillway elevation, and water level varies from year to year. The proposed new smolt outlet structure would likely accommodate outmigrating Pacific lamprey macropthalmia if successful reproduction occurred in upstream tributaries.

5.3.2 Kachess Dam

Kachess Dam is located at RM 1on the Kachess River, a tributary to the Yakima River. This is not as high a dam as Cle Elum or Keechelus Dam, so if it were deemed necessary to provide passage for adult Pacific lamprey at this facility there would be less elevational distance for a LPS to overcome, or trap and haul of adult Pacific lamprey. Getting juveniles out of the reservoir would be a potential problem due to the submerged outlet works and long channel leading to it and with the high pressure associated with the outlet. The Phase I report indicated that about 2.4 miles of suitable salmonid spawning habitat would be accessible if access were provided (Reclamation 2003).

5.3.3 Keechelus Dam

Keechelus Dam is located at RM 214.5 on the Yakima River near Hyak, Washington. Spring Chinook salmon spawn about 0.25 mile downstream from the dam's outlet. The outlet channel of Keechelus Dam is roughly 10 m wide and has a substantial flow. Relative to Pacific lamprey passage, any upstream migrating adults would be confined to the narrow channel. If deemed necessary to provide upstream adult Pacific lamprey passage, a LPS could be positioned with an entrance in lower velocity water downstream from the concrete channel. An adult LPS at this dam would have to be a long structure and overcome a large elevational difference from the river below up and over the dam, to provide upstream passage for adults, and most likely water would have to be pumped into the LPS. Since the reservoir water level fluctuates seasonally, a structure to allow egress of juveniles from the reservoir would be problematic. If adult Pacific lamprey did make it upriver and into the reservoir, they would need to find their way through the reservoir to suitable spawning habitat in tributaries. If spawning were successful, the juveniles would rear in the sediments in the tributaries for as long as seven years before transforming into macropthalmia and beginning an active outmigration. The macropthalmia would need to travel through the lake to the intake tower to continue downstream. The Phase I report (Reclamation 2003) indicated that about 13.8 miles of suitable salmonid spawning habitat would be accessible if access were provided. Time of arrival of adult Pacific lamprey up the Yakima River to this storage facility would have to be estimated. This water storage facility is high in the basin at elevation 2,518 feet and winters are generally severe in this area. Overwintering conditions for juvenile rearing lamprey would be harsh. A screw trap located about 150 m downstream from outlet was operated for the first time in 2010 for sampling fish, specifically bull trout, exiting Keechelus Dam.

Keechelus, Kachess and Cle Elum reservoirs would all generally have low water levels in late summer when adult Pacific lamprey would be migrating this far upstream in the Yakima River. If a trap and haul adult salmonid system is built at Cle Elum Dam, adult Pacific lamprey, if trapped, could be moved up into the reservoir and released. If a LPS is selected as the mechanism to move adult Pacific lamprey up and over the dam, then a long exit ramp down to reservoir water level would be necessary to accommodate these lower water levels. The size and structure of most of the upper basin projects could probably accommodate the placement of radio tracking equipment if needed.

5.3.4 Tieton Dam and Rimrock Reservoir

Tieton Dam is a large and high dam located on the Tieton River at RM 21.3. This is the only major water storage project that is not an enlarged natural glacial lake. At this time there is no provision for upstream fish passage. Fish could migrate downstream past the dam if they could sound and find their way to the outlet works, but they would be subjected to substantial pressures. Reclamation's Technical Service Center Fisheries Resources Research Group, Denver, Colorado, sampled the outflow of Tieton Dam for bull trout and captured four in 2001, eight in 2002 and six in 2003, indicating that at least some fish can exit the reservoir through the outlet works.

The Tieton Dam spillway operates when the reservoir is full, which is another potential downstream passage route for migrating fish. The concrete spillway is long, and depending on the depth of the water in the spillway, injury to fish could occur. A water management operation in the Yakima Basin called flip-flop occurs each year in which releases of water from Naches River water storage projects are held back early on in the irrigation season with most of the releases coming from the upper Yakima River, then in early September those upper Yakima River flows are ramped down and flows from the Naches River are ramped up over a period of about 10 days. This operation is designed to ensure that spring Chinook salmon that spawn in the Yakima River in the fall spawn when water levels are lower and so that their redds will not be dewatered by low flows later in the season.

If Pacific lamprey reintroduction and reproduction was successful above Tieton Dam, any outmigrating juvenile lamprey would have to travel the length of the reservoir and would be subject to predation by resident fish, and then either find the spillway or sound to the deep intake for the powerplant on the dam. Upstream migrating adult lamprey might be attracted to the powerplant outlet or the channel from the spillway. If any adult Pacific lamprey upstream passage were to be considered for Tieton Dam, radio-tagging and tracking of adults would be necessary to determine the approach route to the dam and where to locate either a LPS or other type of structure.

5.3.5 Clear Creek Dam

Clear Creek Dam forms Clear Lake and is located at RM 7.3 on the Tieton River, upstream from Tieton Dam. This smaller dam and reservoir is not likely a candidate for Pacific lamprey passage since it is upstream from Tieton Dam, which does not have fish passage and on which installation of an adult Pacific lamprey passage structure would be difficult. But Clear Creek Dam has a Denil fish ladder on the downstream half of the spillway and a notch and orifice type fish ladder on the upper part of the spillway. The passage structures were designed principally to provide bull trout passage from Rimrock Lake to tributaries upstream from Clear Creek Dam. Any passage opportunities for Pacific lamprey would likely be at the spillway, since there are limited opportunities to install an upstream adult lamprey passage structure at the dam itself. But again, this dam is high up in the basin above impassable Tieton Dam, and adult Pacific lamprey are not expected to be present.

5.3.6 Bumping Lake Dam

Bumping Lake Dam forms Bumping Lake and is located at RM 17.0 on the Bumping River, tributary to the Naches River. This structure as currently configured is a barrier to adult Pacific lamprey passage. The dam has no fish ladder and no passage opportunities exist for adult upstream fish passage, although Bumping Lake Dam is being considered for installation of anadromous fish passage facilities (Reclamation 2003). If this occurs, the design of any upstream anadromous fish passage structure should include provisions for passing adult Pacific lamprey, such as appropriate flow velocity, rounded corners, etc. Juvenile fish might pass downstream in the spillway flow, since this lake spills every year, unlike other Yakima Basin projects that have greater storage volumes and that do not necessarily fill and spill every year. The outlet works might also pass outmigrating juvenile Pacific lamprey, if the juveniles could find the intake tower and deal with the high flow velocity. Since Pacific lamprey are not known to occur this far up in the Yakima basin (Wydoski and Whitney 2003; Mayo 2010) Reclamation recommends that efforts to restore or reintroduce Pacific lamprey be focused at lower Yakima River basin projects.

5.3.7 Conclusions Regarding Upper Yakima Basin Water Storage Facilities

Based on the Yakima River Pacific lamprey distributional information presented in Wydoski and Whitney (2003) and the USFS review of upper Yakima River fish distribution databases (Mayo 2010), Pacific lamprey may not have occurred as far up in the Yakima Basin as Reclamation's water storage projects at the time of the surveys. At this time it would be more cost effective and biologically sound to focus restoration efforts and available resources on adult and juvenile Pacific lamprey passage and restoration issues at lower Yakima River locations. It would be important to consider flows in the Yakima River during the adult upstream migration when considering passage issues and potential passage impediments for adults and juveniles. If Pacific lamprey restoration efforts successfully re-establish populations that may use these upper basin habitats, it would be useful to reanalyze these upper basin project effects and opportunities.

5.4 Yakima Basin Recommendations

The radiotelemetry study planned for the Yakima basin should be conducted and scoped in a manner to inform further recommendations for lamprey conservation efforts at Reclamation projects. The currently low numbers of Pacific lamprey in the Yakima basin poses a challenge in locating enough adults for the radiotelemetry study. Yakima basin adults could be collected through a trapping effort targeting Horn Rapids and Prosser dams. Additional adults may be collected further down the Columbia River basin and moved up to the Yakima area for release. It could be beneficial to the study to collect adults throughout the year and provide simple facilities in which to overwinter them; Prosser dam may provide an opportunity for overwintering adults.

Due to the currently low numbers of Pacific lamprey in the Yakima basin, translocation of adults may be needed in the future to reestablish populations. Additional studies are needed to determine the effects of translocation on the Pacific lamprey populations in the Columbia River basin and determine if this is an appropriate tool for recovery of Yakima basin populations. There may also be opportunities to assist the Yakama Nation with both translocation and propogation such as providing rearing or overwintering habitat within project facilities, as well as funding support, and these options should be explored further.

LPSs have successfully provided passage for adult Pacific lamprey at lower Columbia River hydropower projects. Since LPSs are relatively simple structures in design and operation, they should be considered for installation where data indicates the need. Their specific location at each of the facilities should be informed by results of the adult Pacific lamprey radio-tracking study expected to begin in 2011. There is little information about the population dynamics of Pacific lamprey in the Yakima River and the radio tagging and tracking study should provide substantial new information that can be used to understand Pacific lamprey behavior in the basin as well as where best to locate entrances to LPSs. Initial efforts to restore Pacific lamprey populations in the Yakima River should be focused in the lower river, since addressing and overcoming impediments to adult and juvenile passage and potential spawning and rearing habitat are more likely to benefit the population than actions at upstream projects, at this time.

Juvenile lamprey have been documented at the Chandler Juvenile Fish Facility but at the present time staff operating the facility do not have sufficient time or resources to collect, count and identify the juveniles to species, or collect other pertinent biological information such as size. The Fish Passage Center is planning to expand its Smolt Monitoring Program to include a more systematic assessment of juvenile lamprey collected in the juvenile fish facilities (Chockley 2010). Information about the timing of migration and seasonal abundance will be an important step in understanding the dynamics of downstream migration and in developing an approach to protecting outmigrating juveniles. Details about the timing of migration will inform additional studies to determine potential passage timing at upstream projects, and how effective the existing rotating drum screens are in guiding migrating juveniles back to the river, or if the existing fish screens designed to NMFS criteria for juvenile salmonids are adequate for juvenile Pacific lamprey (NMFS 1997). There is a need to determine when and where juvenile Pacific lamprey occur in the system and then determine the effectiveness of existing juvenile bypass screens, and therefore the potential for entrainment into canals and the potential loss of Pacific lamprey to the population. Surveys behind fish screens should be conducted where entrainment of lamprey is suspected, and if juveniles are found, the mechanism and magnitude of entrainment should be evaluated. These studies should be prioritized by facility where the highest likelihood of juvenile entrainment exists. Ongoing studies to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey should continue.

6.0 UMATILLA RIVER BASIN PROJECTS

The Umatilla River is a smaller basin than the Yakima River basin, but it has similar Pacific lamprey passage issues and constraints. The Umatilla Basin is about 2,290 square miles, at UMAO, the site of the USGS gauge 2.1 mile above the mouth. Monthly discharge ranges from 31 cfs in August to 1,300 cfs in April.

Site visits to Three Mile Falls and Feed Canal Diversion dams were made within the last two years, and information from those visits as well as information from formal and informal meetings and discussions with Tribal and other agency staff and biologists was used in this assessment (Figure 13). In an attempt to restore Pacific lamprey populations in the Umatilla River basin, the CTUIR has translocated adult Pacific lamprey upriver since 2000 to jump-start restoration of the population. The CTUIR Pacific lamprey translocation program releases adult Pacific lamprey upstream in the basin above Pendleton, Oregon. This program has shown some initial success. Yakama Nation biologists are considering implementing a similar program in the Yakima Basin.

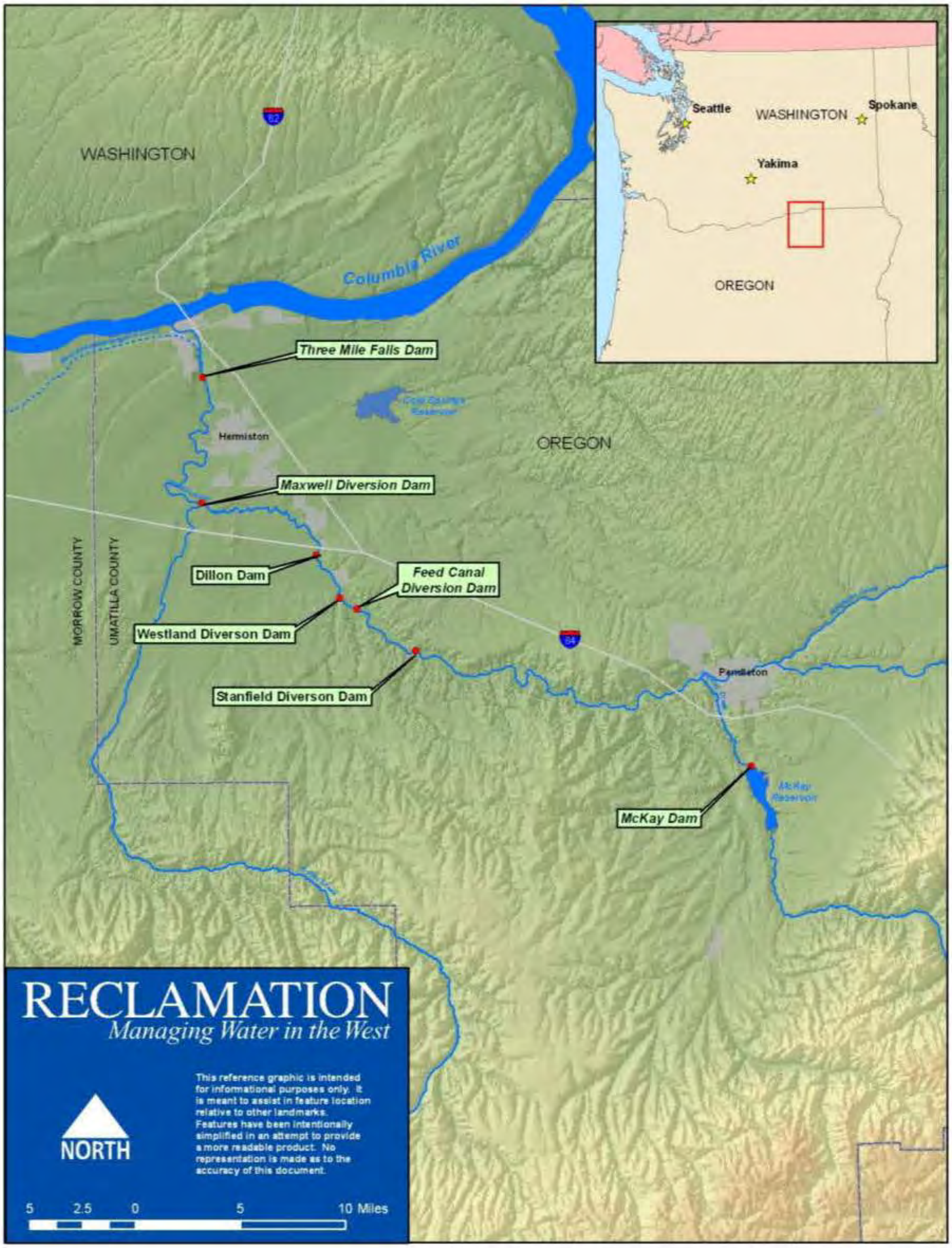

Figure 13. Map of Umatilla River basin.

Discussions with local Tribal and federal biologists working on the Umatilla River provided information indicating that adult Pacific lamprey had problems passing Three Mile Falls Dam as well as other structures further upstream, and an ongoing radio telemetry study has been conducted since 2005 in the basin to evaluate passage efficiency for upmigrating adult Pacific lampreys. This study has determined that even low-elevation diversion dams block or impede lamprey passage to upstream spawning grounds (Moser et al, 2007).

They also indicated that lamprey ammocoetes, most likely Pacific lamprey, were found in canals downstream from irrigation diversions. Abundance and distribution of lamprey ammocoetes in canals has not been assessed, although this information is important to the Tribe and is a high priority task for CTUIR (Jackson 2009). The information is necessary to determine the extent or magnitude of the potential loss to the population through diversion into canals.

This discussion of Reclamation and non-Reclamation water diversion projects in the Umatilla Basin will be from downstream to upstream, the order in which an upstream migrating adult Pacific lamprey would encounter the projects. Reclamation diversion projects will be discussed first, followed by the non-Reclamation diversion projects. Table 8 provides an overview of major Umatilla Basin irrigation diversion and storage facilities; detailed discussion follows below. The discussion will include information regarding conditions potentially affecting Pacific lamprey passage, as well as opportunities for implementing upstream and downstream passage improvements, such as installation of LPSs.

6.1 Reclamation Diversion Facilities

6.1.1 Three Mile Falls Dam

Three Mile Falls Dam and diversion at RM 3 on the Umatilla River is a concrete multiple arch weir structure that diverts water through the West Extension Irrigation District Main Canal to irrigate 6,519 acres of project lands. The dam was completed 1914. It has a structural height of 24 feet, and crest length of 915 feet. A new fish ladder on the dam’s east bank was constructed in 1987. The WEID Canal fish screens and trapping facilities were constructed in 1988. The canal has a design capacity of approximately 270 cfs, though only 150-175 cfs are normally diverted. A west bank fish ladder had been constructed previously. BPA owns the fish protection and passage facilities, and contracts maintenance of the fish screens and fish ladders through WEID. Oregon Department of Fish and Wildlife (ODFW) and CTUIR operate a smolt sampling facility and adult fish collection and monitoring facilities at the dam. A LPS was installed on the east side of the dam in July 2009 to facilitate upstream passage of adult Pacific lamprey. Adult upmigrating lamprey were forced to climb up and over the dam crest or utilize a fishway designed for upmigrating salmonids prior to the completion of the LPS. Through the use of radio tagged adult lamprey the CTUIR was able to determine the appropriate location for the LPS placement at Threemile Falls Dam. About 20 adult Pacific lamprey used the LPS in 2010.

Figure 14. Three Mile Falls Dam.

Juvenile outmigrating lamprey are expected to pass this diversion. The fish screen facilities were constructed to protect salmonids, and their effectiveness at protecting lamprey from entrainment is not known. Lamprey could be impinged on the screen or attach to the screen and be carried up and over into the canal with the drum rotation. Surveys behind the screens would investigate the presence or absence of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted.

6.1.2 Maxwell Diversion Dam

The Maxwell Diversion Dam diverts water from the Umatilla River at RM 15.5 one mile west of Hinkle, Oregon, and conveys it to lands within Hermiston Irrigation District. The dam is a concrete and timber crib weir with an embankment wing completed 1912. The dam provides diversion into the 10 mile-long Maxwell Canal. It is only about one foot high, so a fish ladder is not needed for passage of adult salmonids. Flashboards are usually installed by early to mid April (near the end of peak adult steelhead migration), and usually taken out by mid

September (before the peak adult salmon migration), so the flashboard are in during lamprey migration periods. New canal fish screens were constructed in 1989. A flat plate ramp was installed at Maxwell Diversion Dam during the summer of 2010 to provide a passage route for Pacific lamprey. The ramp is a 2-foot-wide piece of aluminum with rolled upstream and downstream edges.

Figure 15. Maxwell Diversion Dam.

Juvenile outmigrating lamprey are expected to pass this diversion, and juvenile lamprey have been observed in the vicinity during salvage operations. The fish screen facilities were constructed to protect salmonids, and their effectiveness at protecting lamprey from entrainment is not known. Lamprey could be impinged on the screen or attach to the screen and be carried up and over into the canal with the drum rotation. Surveys behind the screens would investigate the presence or absence of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted. Reclamation plans to cooperate with Tribal fisheries biologists in surveying some selected canals in future years after diversions are shut off for the year. Maxwell Diversion Dam operates from April until mid to late September, so some sampling could be scheduled there in the fall.

6.1.3 Feed Canal Diversion Dam

The Feed Canal Diversion Dam is located on the Umatilla River at RM 29, 1.5 miles southeast of Echo, Oregon. It was completed by Reclamation 1907. The dam raises the level of the water in the riverbed 4 feet to divert water into the 25-mile long Feed Canal that extends to Cold Springs Reservoir. A new fish ladder at the dam, and canal fish screens were constructed in 1990. A modification was made to the dam in 2008 to improve upstream adult fish passage; a notch was cut in the dam to facilitate salmonid passage, and the notch and existing fish ladder were outfitted with PIT-tag detectors. A rock weir fish passage channel was constructed just downstream to allow adult salmon and steelhead easier access to the notched dam and fish ladder. NOAA Fisheries, Pasco Field Office, with input from CTUIR and NOAA Fisheries biologists and engineers and some funding from Reclamation, designed a LPS to improve adult Pacific lamprey passage at Feed Canal Diversion Dam, and this structure was installed in November 2010.

Figure 16. Feed Canal Diversion Dam with lamprey ramp installed.

Juvenile outmigrating lamprey are expected to pass this diversion, and juvenile lamprey have been observed in the vicinity during salvage operations. The fish screen facilities were constructed to protect salmonids, and their effectiveness at protecting lamprey from entrainment is not known. Lamprey could be impinged on the screen or attach to the screen and be carried up and over into the canal with the drum rotation. Surveys behind the screens would investigate the presence or absence of juveniles. If juveniles are found, further investigations could determine the extent and the mechanism of entrainment. The ongoing studies to test screen effectiveness, refine screen criteria, and test guidance techniques to deter lamprey from the diversion should provide information to pursue possible solutions to juvenile entrainment if found to be warranted. Reclamation plans to cooperate with Tribal fisheries biologists in surveying some selected canals in future years after diversions are shut off for the year. Feed Canal Diversion Dam generally stops diverting water sometime in April, so sampling of that canal would need to be scheduled for April.

6.2 Non-Reclamation Diversion Facilities

The non-federal projects described below are generally similar to Reclamation projects in size, construction, complexity and have a similar range of issues and opportunities for improving adult and juvenile Pacific lamprey passage.

6.2.1 Dillon Diversion Dam and Canal

The diversion dam is located at RM 24. Water diversion activities at Dillon Diversion Dam and Canal have no federal connection nor use any federally stored water. A new fish screen that meets NOAA Fisheries screening criteria was constructed at the Dillon diversion. Two fish ladders are present at the dam, but as river flows drop, only one remains watered up and functional. A simple LPS was installed at Dillon Diversion Dam in 2011.

Figure 17. Dillon Diversion Dam.

6.2.2 Westland Diversion Dam and Canal

The Westland Diversion Dam at RM 28 diverts natural Umatilla River flows and supplemental storage water from McKay Reservoir. The dam structure and canals are private facilities owned and maintained by Westland Irrigation District (WID). A new fish ladder at the dam, and canal fish screens were constructed to NOAA Fisheries criteria in 1991. BPA owns the fish protection and passage facilities, and contracts the operations and maintenance of the fish screens and fish ladder through WID. Some limited sampling by CTUIR biologists has documented Pacific lamprey ammocoetes in the canal downstream from the fish screens. The CTUIR has placed a high priority on determining the presence and distribution of Pacific lamprey ammocoetes in irrigation canals, to document possible entrainment of juvenile Pacific lamprey into the canals and potential loss to the population.

Figure 18. Westland Diversion Dam.

6.2.3 Stanfield (Furnish) Diversion Dam and Canal

The Stanfield Diversion Dam at RM 33 diverts natural Umatilla River flows and supplemental McKay Reservoir water into Stanfield Irrigation District's canal system. The dam structure and canals are private facilities owned and maintained by SID. The Stanfield Canal fish screens and fish ladder at the dam are Federal facilities owned by BPA, and meet NOAA Fisheries screening criteria. Operations and maintenance of fish protection facilities is contracted to Westland Irrigation District, funded by BPA. No adult Pacific lamprey passage structure is planned for Stanfield Dam at this time.

Figure 19. Stanfield Diversion Dam.

Both actively downstream migrating juvenile Pacific lamprey (macropthalmia) and passively migrating ammocoetes could possibly be diverted into the irrigation canals at the several diversions, although the extent of entrainment into canals has not been evaluated. Macropthalmia are mostly on an active downstream migration while ammocoetes for the most part are moving passively in response to seasonal high flows that disrupt or scour the substrate. Ammocoetes entrained in these flows could be diverted into irrigation canals if the canals operate at that time. If these entrained ammocoetes cannot get back to the river, they are essentially lost to the population. Larger ammocoetes or macropthalmia would more likely be guided to a fish bypass than younger one- or two-year-old ammocoetes. Fish screens are in place in Feed and Maxwell canals, but they have not been evaluated for returning juvenile lamprey back to the river. Size at age of a larger sample of juvenile Pacific lamprey would inform decisions regarding screen size needed to protect downstream migrants and improve survival. The average length of 10 juvenile Pacific lamprey used in the preliminary tests of a behavioral guidance device at the mouth of McKay Creek near Pendleton in July 2009 was 121 mm, body depth was 7.47mm, and body width was 5.88 mm. These ammocoetes were likely several years old.

6.3 Reclamation Water Storage Projects

6.3.1 McKay Dam and Reservoir

McKay Dam is located at RM 6 on McKay Creek, a tributary of the Umatilla River near Pendleton, Oregon. The dam is impassable to salmon and steelhead. Some juvenile steelhead rear in the creek, although a screen at the mouth of the creek is designed to eliminate the upstream passage of adult salmon and steelhead into the creek. Pacific lamprey may have occurred in the creek historically. Due to the height of the dam and Pacific lamprey restoration efforts focused on the mainstem Umatilla River, no effort is underway to translocate Pacific lamprey upstream above McKay Dam. However, if passage upstream is provided for adult salmonids in the future, considerations for adult and juvenile lampreys should be included.

6.4 Umatilla River Basin Recommendations

In the Umatilla River basin, LPSs have been installed at Three Mile Falls Dam and Feed Canal Diversion Dam, and a flat plate passage has been installed at Maxwell Diversion Dam. The effectiveness of structures on Reclamation projects should be monitored. LPSs could be considered for installation at other projects on the Umatilla River, since these are relatively small structures. Placement and design should be developed with site specific data.

At the present time there is sparse information about aspects of downstream migration of juvenile Pacific lamprey in the Umatilla River. Information about the migration timing and abundance of juvenile Pacific lamprey would be important in understanding the dynamics of migration and in developing a plan to protect outmigrating juveniles from entrainment into diversions. There is a need to determine when and where juvenile lamprey appear in the system and then determine the effectiveness of existing juvenile fish screens, and therefore the potential entrainment into canals and the potential loss of lamprey to the population. Ongoing studies to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey should continue. Continued sampling and/or entrainment studies of project canals should be done to help determine the extent of entrainment and screen mortality issues, as well as prioritize projects for further study and to outline actions to reduce effects to Pacific lamprey. These larval lamprey surveys should be completed behind the fish screens at Three Miles Falls, Feed Canal, and Maxwell diversions, with the outcome of those surveys setting priority for further study to determine extent and mechanism of entrainment, leading to identification of possible actions to address entrainment.

7.0 OTHER BASIN PROJECTS

While the focus for this assessment and recommendations for further efforts is Reclamation' projects in the Yakima and Umatilla River, there are other Reclamation projects in the Columbia basin that may also affect Pacific lamprey. These projects, in the Deschutes, Tualatin, and Snake River Basins, are described in this chapter with some preliminary observations of any associated lamprey issues.

7.1 Deschutes River Basin

Water development and irrigation projects and operations in the Deschutes River Basin are unique and different from those described above in the Yakima and Umatilla basins in that in the Deschutes Basin, Reclamation, along with private entitites (irrigation districts), owns and/or operates components of three separate irrigation projects, the Deschutes and the Crooked River projects in the upper Deschutes Basin (in 4th-field HUCs 17070301, Upper Deschutes and 17070305, Lower Crooked, respectively) above the Pelton-Round Butte dam complex and the Wapinitia Project on the White River, a westside tributary of the lower Deschutes River (in 4th-field HUC 17070306 Lower Deschutes). Figure 7.1 shows several irrigation and related structures in the Deschutes River basin. In a complicated arrangement of ownership and operation, Reclamation owns and operates some of the water storage facilities and distribution systems and headworks, but not the in-river diversion structures themselves. Private entities operate the diversion structures and some storage and distribution facilities. This section will describe the features of these several irrigation projects in the Deschutes Basin, with the intermingled project ownership and operations and where Reclamation structures might be impediments to upstream or downstream migration of Pacific lamprey. Table 7.1 shows owner and operator of the various facilities and will be described in more detail below. A detailed account of operations of the Deschutes River projects can be found in Reclamation (2003) and at:

- http://www.usbr.gov/projects/Project.jsp?proj_Name=Deschutes+Project
- http://www.usbr.gov/projects/Project.jsp?proj_Name=Crooked+River+Project
- http://www.usbr.gov/projects/Project.jsp?proj_Name=Wapinitia+Project

With regard to Pacific lamprey migration in the river, and the potential effects of in-river structures on migration, the focus of this assessment, two of the three projects are located in the upper Deschutes River basin, upstream from the Pelton-Round Butte dam complex. Both anadromous salmonids and Pacific lamprey are currently excluded from the upper basin by the Pelton-Round Butte dams operated by Portland General Electric, and are restricted to the

100 miles of the river and tributaries below Pelton reregulating dam. Kostow (2002) noted that Pacific lamprey occurred in the Crooked River in the upper Deschutes Basin, but they are now absent above the Pelton-Round Butte dam complex. These species occurred historically throughout some regions of the Deschutes River basin and Pacific lamprey are thought to have occurred historically pretty much wherever anadromous salmonids occurred. Sherars Falls at RM 43 is passable by salmon and steelhead and presumably adult Pacific lamprey.

There have been some recent efforts to reintroduce anadromous salmonids in the upper basin, especially steelhead in the Crooked River. These efforts might eventually be expanded to include reintroduction or translocation of Pacific lamprey upstream. If anadromous salmonid reintroduction is successful and if passage structures such as ladders are designed and constructed, provisions for adult and juvenile Pacific lamprey passage should be considered in the design of passage facilities.

The abundance of Pacific lamprey in the Deschutes Basin is reduced from historic numbers, based on information that Native Americans harvested substantial numbers at Sherars Falls but now must harvest adult Pacific lamprey at Willamette Falls on the Willamette River (CRITFC 2008).

The Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) has expressed several overall goals for improving Pacific lamprey management and conservation in the Deschutes Basin, including: "1) continued monitoring of adult, larval, and outmigrant populations below PRB; 2) annual monitoring of harvest and escapement above Sherars Falls; 3) expansion of knowledge on life history, habitat requirements, population dynamics, and sampling techniques for all life stages; 4) evaluation of both upstream adult and downstream juvenile passage through PRB; 5) restoration of historic lamprey distribution above PRB; and 6) development and implementation of lamprey-specific restoration projects that augment habitat and directly address limiting factors" (CTWSRO 2008). If salmonid reintroduction into the upper basin upstream of Pelton-Round Butte complex is successful, and if Pacific lamprey are reintroduced to the upper basin, adult and juvenile passage could become issues at Reclamation and private irrigation projects there.

7.1.1 Deschutes Project

The Deschutes Project provides irrigation water to lands near Madras, Oregon. Principal Reclamation features of the project include the water storage facilities Crane Prairie Dam and Reservoir, Wickiup Dam and Reservoir, and Haystack Dam and Reservoir; North Unit Main Canal and lateral system; and the Crooked River Pumping Plant. All of these projects features are located upstream from the Pelton-Round Butte dam complex.

Reclamation Storage Facilities

Crane Prairie Dam and Reservoir

Crane Prairie Dam is an earthfill structure 36 feet high and 284 feet in length that was rehabilitated by Reclamation in 1940. It is located about 2 miles above Wickiup Reservoir on the Deschutes River. It does not have fish passage facilities. The reservoir has a total capacity of 55,300 acre-feet (active 55,300 acre-feet). The reservoir has about 4,940 acres of water surface with about 24 miles of shoreline. The spillway is an uncontrolled weir in the floor of an open cut channel in the left abutment. The right wall of the spillway was raised 9 feet in 1992 to enable passage of 60 percent of the probable maximum flood without overtopping the dam. This reservoir is the highest up in the system and releases water into Wickiup Reservoir.

Figure 20. Crane Prairie Dam

Wickiup Dam and Reservoir

Wickiup Dam and Reservoir are located on the main Deschutes River about 35 miles southwest of Bend, Oregon, downstream from Crane Prairie Dam. It provides water storage for the irrigation of lands in the North Unit Irrigation District. The dam is 100 feet high, with a crest length of 13,860 feet, and was completed in 1949. The dam was built by a private entity before Bureau of Reclamation construction work began. It does not have fish passage facilities. The reservoir has a total capacity of 200,000 acre-feet (active 200,000 acre-feet). The East Dike closes a low area on the east side of the reservoir, and has a crest length of 3,420 feet. The spillway is an open rock cut with concrete sill at the north end of the East Dike.

Releases from the reservoir are diverted from the Deschutes River at North Canal Dam near Bend. Water is carried to project lands by the North Unit Main Canal and distributed through a system of laterals. Water stored in Crane Prairie Reservoir is also diverted by the North Canal Dam into other privately built delivery and distribution systems operated by Central Oregon Irrigation District and Crook County Improvement District No. 1.

Wickiup Reservoir has about 11,200 acres of water surface, with about 48 miles of shoreline.

Figure 21. Wickiup Dam and Reservoir.

Haystack Dam and Reservoir

Because of the long distance from Wickiup Reservoir to the irrigated projects lands of the North Unit, a regulatory reservoir was required to provide more rapid response to irrigation demands. Storage provided by the 5,600 acre-foot Haystack Reservoir addressed this need. Haystack Dam is an offstream storage facility located about 10 miles south of Madras, Oregon, completed in 1957. The dam is an earthfill structure 105 feet high with a width of 25 feet and length of 1,200 feet. Water stored in Wickiup Reservoir is diverted from the North Unit Main Canal near Bend, Oregon. Haystack also receives water from the Crooked River Pumping Plant, located where the North Unit Main Canal crosses the Crooked River. Releases from Haystack Reservoir flow in a feeder canal back to the North Unit Main Canal for use in the service area. The feeder canal also acts as a spillway. Haystack Reservoir has about 233 acres of water surface, with 5 miles of shoreline.

Figure 22. Haystack Dam and Reservoir.

7.1.2 Diversion Facilities and Features

Reclamation does not own or operate diversion facilities for the project. Diversion occurs at the privately owned North Canal Dam into a Reclamation-owned distribution system, as well as to several other privately owned facilities.

North Unit Main Canal

The North Unit Main Canal, with an initial capacity of 1,000 cubic feet per second, heads at the privately owned North Canal Dam near Bend and extends about 65 miles to the vicinity of Madras. Besides the canal itself, other structures include a concrete flume crossing Crooked River Gorge, and two tunnel sections in the vicinity of Smith Rock that have an aggregate length of 1.3 miles.

Crooked River Pumping Plant

The North Unit Irrigation District constructed a pumping plant in 1968 adjacent to and at the point where the North Unit Main Canal crosses the Crooked River. The purpose of the pumping plant is to furnish a supplemental water supply, when needed, by pumping from the Crooked River and discharging into the North Unit Main Canal. The plant consists of nine vertical shaft pumps with a total capacity of 200 cubic feet per second at a total dynamic head of 150 feet.

Deschutes Project Pacific Lamprey

At this time Pacific lamprey are excluded from the upper Deschutes River by the Pelton-Round Butte dam complex. The privately owned North Canal Dam diverts water stored in Crane Prairie and Wickiup reservoirs into the North Unit Main Canal. Since Pacific lamprey have been excluded from the upper Deschutes Basin for a substantial period of time, it is not known where the adults would spawn and where juveniles would rear, although some assumptions could be made based on habitat requirements for these life history stages from other basins where Pacific lamprey do occur, including the lower Deschutes River and the Umatilla River. It is not known if Pacific lamprey would occur as far upstream as the two water storage reservoirs, but if they would, the lack of fish passage at the dams would be an impediment to further upstream migration.

7.1.3 Crooked River Project

The main portion of the irrigated lands of the Crooked River Project lies north and west of Prineville, Oregon. Water from Ochoco Creek and Crooked River provide irrigation water for approximately 20,000 irrigated acres. The Ochoco Project was constructed by private interests in cooperation with the State of Oregon during 1918-1921. Crooked River Project features include Arthur R. Bowman Dam on the Crooked River, Ochoco Dam on Ochoco Creek, a diversion canal and headworks on the Crooked River, Lytle Creek Diversion Dam and Wasteway, two major pumping plants, nine small pumping plants, and Ochoco Main and distribution canals.

Water Storage Facilities

Arthur R. Bowman Dam and Prineville Reservoir

Arthur R. Bowman Dam (also known as Prineville Dam) is a Reclamation-owned facility located on the Crooked River about 20 miles upstream from Prineville, Oregon. The dam was completed in 1961 and is 245 feet high, with a crest length of 800 feet. The initial total capacity of Prineville Reservoir was 154,690 acre-feet (active 152,800 acre-feet), since reduced to 150,200 acre-feet (active 148,600 acre-feet) by sedimentation. The spillway consists of an uncontrolled-crest inlet structure, chute, and stilling basin. Capacity of the spillway is 8,120 cubic feet per second at maximum water surface elevation of 3,257.9 feet. The capacity of the outlet works is 3,300 cubic feet per second at normal water surface elevation of 3,234.8 feet. The Prineville Reservoir has a reservoir surface area of 3,030 acres, with about 43 miles of shoreline. The dam does not have fish passage facilities. A trout fishery has developed in the Crooked River downstream from the dam. Water stored in Prineville Reservoir is released into the river and diverted to project lands by a diversion canal 6 miles above Prineville.

A minimum release of 10 cubic feet per second is maintained from the reservoir for fish in the river below the dam when there is no other discharge, but this release may be reduced for brief periods if it is determined that the release of the full 10 cubic feet per second is harmful to the primary purpose of the project.

Figure 23. Arthur R. Bowman Dam and Reservoir.

Ochoco Dam and Reservoir

Privately-owned Ochoco Dam is located on Ochoco Creek 6 miles east of Prineville; Ochoco Irrigation District retains title to the dam. The original dam was constructed after World War I as a part of the Veterans Farm Settlement Program undertaken by the State of Oregon and is about 126 feet high and 1,000 feet long, with an average crest width of 15 feet. Reclamation rehabilitated the dam in 1949 and increased the reservoir capacity. The repaired and reconstructed dam is 125 feet high with a crest length of 1,350 feet. The spillway is an open concrete chute at the south end of the dam. The dam provides flood control of Ochoco Creek as well as water for irrigation.

Work under the Safety of Dams Program was initiated in 1994 and completed in 1998. Work included, among other things, installation of an upstream interceptor trench and drainage system, replacement of riprap on the upstream face of the dam, a new outlet works, and spillway modifications. As part of this work, the intakes in the outlet tower were raised. This work, together with findings of a 1990 sedimentation survey, resulted in an active reservoir capacity of 39,600 acre-feet at spillway crest elevation 3130.7 feet.

Figure 24. Ochoco Dam and Reservoir.

The project provides water for irrigation to the Ochoco Irrigation District. Releases from Ochoco Reservoir flow into the Ochoco Main Canal, which serves high-elevation project lands east and north of Prineville. From the headworks, the diversion canal runs north 8.3 miles across Ochoco Creek to the Barnes Butte Pumping Plant. The diversion canal serves irrigable lands along its course.

Diversion Facilities and Features

The Ochoco Irrigation District operates the project facilities, which consist of Lytle Creek Diversion Dam and Wasteway, Barnes Butte Pumping Plant, the distribution canal, the Ochoco Relift Pumping Plant and Extension Pumping Plants.

Lytle Creek Diversion Dam and Wasteway

Lytle Creek Diversion Dam is a rockfill structure with timber cutoff and embankment wing on Lytle Creek near Prineville. The dam has a streambed height of 4 feet, a crest length of 200 feet, and diversion capacity of 72 cubic feet per second. Lytle Creek Diversion Dam and Wasteway capture return flows from project lands in the Lytle Creek area and divert them into the project-built Rye Grass Ditch.

The wasteway heads at Lytle Creek Diversion Dam, have an initial capacity of 160 cubic feet per second, and empty into Rye Grass Ditch. Headworks are controlled by one 18-inch and two 36- inch slide gates.

Barnes Butte Pumping Plant

Barnes Butte Pumping Plant lifts a maximum of 147 cubic feet per second from the end of the diversion canal to the head of the distribution canal. The pump site is at the foot of Barnes

Butte, about 0.75 mile east of the city limits of Prineville. The Barnes Butte Pumping Plant lifts water to the distribution canal which runs through the center of the district lands.

Distribution Canal

The Distribution Canal serves all Ochoco District lands west of Barnes Butte below an elevation of 2,950 feet and above Rye Grass Ditch. In addition, the canal carries water lifted by Ochoco Relift Pumping Plant to Ochoco Main Canal near McKay Creek to serve lands below this main canal. The distribution canal carries water about 15.8 miles in a northerly direction and has an initial capacity of 102 cubic feet per second.

Ochoco Relift Pumping Plant

The Ochoco Relift Pumping Plant pumps a maximum of 80 cubic feet per second from the distribution canal to replenish flows in the Ochoco Main Canal to irrigate lands west of McKay Creek. The plant contains four units, operates against a total dynamic head of 99 feet, and produces a total of 1,300 horsepower.

Extension Pumping Plants

Six small pumping plants and associated canals, laterals, and drains were completed to serve the additional acreage in the Crooked River Project Extension. These features serve lands of six separate areas located generally east and north of the original project area. Combs Flat Pumping Plant pumps water from the Diversion Canal, and the Hudspeth Pumping Plant pumps water from the Distribution Canal. The remaining four pumping plants pump from the Ochoco Main Canal. Three smaller pumping plants were later installed in the extension area by the Ochoco Irrigation District. These pumping plants do not pump directly from the river so they should have little or no impact on migrating lamprey.

Crooked River Project Pacific Lamprey

At this time Pacific lamprey are excluded from the Crooked River by the Pelton-Round Butte dam complex. Since Pacific lamprey have been excluded from the Crooked River Basin for a substantial period of time, it is not known where the adults would spawn and where juveniles would rear, although some assumptions could be made based on habitat requirements for these life history stages from other basins where Pacific lamprey do occur, including the lower Deschutes River and the Umatilla River. It is not known how far upstream Pacific lamprey would occur in the basin, but if they would occur up as far as diversion or storage facilities, the lack of fish passage at the facilities would be an impediment to further upstream migration and some form of adult and/or juvenile passage would need to be considered.

7.1.4 Wapinitia Project

The Wapinitia Project, Juniper Division, is on Juniper Flat in north-central Oregon in the White River basin. The White River is a westside tributary that enters the lower Deschutes River at RM 46.4. White River Falls on the White River at RM 2.1 provides a barrier to migrating salmon in the White River, and is likely a barrier to migrating adult Pacific lamprey as well. Juniper Flat is a plateau, 3 to 6 miles wide and approximately 17 miles long, between the Deschutes and White Rivers. Approximately 2,100 acres over a scattered area receive supplemental irrigation flows from the project when the natural flows begin to decrease in July during wet years and as early as April in dry years. The principal project feature is Wasco Dam on Clear Creek, 0.5 mile below the outlet of Clear Lake, a natural lake in a mountain valley.

Project water is stored in Clear Lake behind Wasco Dam, about 35 miles west of Maupin, Oregon. About 5,000 acre-feet of stored water is diverted annually. A diversion structure on Clear Creek, located about 3 miles downstream from Wasco Dam, diverts the water into a delivery canal, through which it is conveyed about 12 miles to McCubbin Gulch. After flowing about 4 miles down the gulch, the water is rediverted into the distribution system. The main distribution canal extends the full length of Juniper Flat north of Wapinitia Creek. Two smaller canals with separate diversions from McCubbin Gulch serve a small area south of Wapinitia Creek. Several other irrigation projects exist in the White River basin, but they do not use federally stored water. These private diversions divert about 21,490 acre-feet annually.

Water Storage Facilities

Wasco Dam

Wasco Dam is a 59-foot-high zoned earthfill structure. The crest is 20 feet wide and 415 feet long. The reservoir has a total capacity of 13,100 acre-feet (active 11,900 acre-feet) and a surface area of 557 acres. The dam does not have fish passage facilities. The outlet works consists of 20-foot-wide approach and outlet channels, a submerged vertical intake structure, a single rectangular 4- by 5-foot conduit, a gate chamber with two 3-foot-square slide gates and two overflow weirs, and a 56-foot-long stilling basin. The slide gates are operated manually by two lifts on top of the gate chamber structure at the crest of the dam. The emergency spillway, crossing the left abutment, consists of an unlined channel with a base width of 30 feet. A concrete overflow grade wall is in the spillway 10 feet upstream of the axis of the dam. The project is operated and maintained by the Juniper Flat District Improvement Company.

Figure 25. Wasco Dam and Clear Lake.

Diversion Facilities

Juniper Flat District Improvement Company (JFDIC) Ditch

The Juniper flat District Improvement Company diverts water from Clear Creek about 3 miles downstream from Wasco Dam. The facilities are generally operated for the irrigation season beginning about April 1 and which ends about October 31. About 5,400 acre-feet are diverted annually including water stored in Clear Lake and some natural flow. Typical diversion during the irrigation season is 20 to 45 cfs.

7.1.5 Pelton-Round Butte Dam Complex

The Pelton-Round Butte dam complex and hydroelectric project is two-thirds owned by Portland General Electric and one-third owned by the CTWSRO. The Reregulating Dam powerhouse is wholly owned by the Tribes. It is a barrier to upstream migration of salmon and steelhead and Pacific lamprey. A 273-foot tall Selective Water Withdrawal tower was completed in 2009 to facilitate juvenile fish collection efforts in the Round Butte Dam forebay and provide downstream passage. This structure has successfully passed tagged juvenile salmonids. It is expected that as salmonid reintroduction actions progress above the complex that the selective withdrawal tower will continue to pass juvenile fish effectively. If Pacific lamprey are sometime in the future successfully reintroduced into the upper Deschutes River Basin, this structure may provide a route for their downstream migration, but this would have to be evaluated.

7.1.6 Pacific Lamprey Passage Issues in the Deschutes River Basin

Reclamation irrigation project features and operations in the Deschutes River are for the most part upstream from Portland General Electric's Pelton-Round Butte Project, which is a barrier to upstream anadromous fish passage, including Pacific lamprey. Pacific lamprey are excluded from the area upstream from the PRB project (Kostow 2002), although upstream migrating adult Pacific lamprey would not encounter substantial barriers in the lower 100 miles of the Deschutes River. They apparently successfully pass Sherars Falls at RM 43.

Some effort has been made recently to reintroduce anadromous salmonids upstream of this project, and a selective withdrawal tower has been constructed in Lake Billy Chinook to attract downstream outmigrating juvenile salmonids and pass them safely downstream. This structure might serve to pass outmigrating Pacific lamprey macropthalmia downstream, but they would still have to pass Pelton Dam. It is unknown how in the future returning adult salmonids from the reintroduction program will pass the Pelton-Round Butte complex to natal spawning grounds. It is likely that adult Pacific lamprey do not pass the Pelton-Round Butte complex. It is unknown at this time if adult Pacific lamprey can pass the project or if there need to be active intervention to reintroduce adult Pacific lamprey upstream of this project. The Wapinitia Project on the White River is upstream from a waterfall that constitutes an impassable barrier to adult salmonids and most likely to adult Pacific lamprey as well.

At the present time, Pacific lamprey cannot pass the Pelton-Round Butte complex to reach suitable habitat upstream in the Deschutes, Metolius and Crooked rivers. In the main Deschutes River, if adult Pacific lamprey do get past the Pelton-Round Butte dam complex, they would first have to migrate through Lake Billy Chinook, then they would have to pass North Canal Dam at RM 164.8, a diversion structure that is likely a migration barrier. As adults progress upstream, they would encounter Central Oregon Diversion Dam at RM 170.9 and Arnold Diversion Dam at RM 174.6 before encountering Wickiup Dam. If Pacific lamprey are successfully reintroduced upstream from the Pelton-Round Butte dam complex, passage devices such as LPSs or LPSs would need to be considered. For downstream migration of juvenile lamprey, depending on where they originate in the system, the juveniles would pass the North Canal Dam, which diverts work into the North Unit Main Canal at RM 164.8, which is owned by Reclamation and operated by NUID.

In the Crooked River, upstream migrating adult Pacific lamprey would first encounter Opal Springs Dam, which is a 20-feet-high hydroelectric facility located on the lower Crooked River in Jefferson County. It was completed in 1985 and has a normal surface area of 5 acres. It is owned by Deschutes Valley Water District. It is a barrier to fish passage. Any adult Pacific lamprey migrating up the Crooked River would encounter this dam before encountering the privately owned Lowline Ditch Diversion and the People's Ditch Diversion before encountering Crooked River Diversion Dam and fish screen near RM 56 about 14 miles below Arthur R. Bowman Dam. If Pacific lamprey are reintroduced into the Crooked River, Opal Springs Dam and the Reclamation and privately owned irrigation diversions would need to be evaluated for opportunities to provide lamprey passage, both upstream and downstream.

Much of the water diverted from the Deschutes River occurs at diversions upstream from and including the North Canal Dam near Bend. As such, there is sometimes little flow downstream from this point, although several irrigation districts have an agreement to provide a flow of at least 30 cfs downstream. If adult Pacific lamprey did make it passed Pelton-Round Butte dam complex into the Deschutes River, they would encounter these lower flows, but low flow itself should not hinder passage, as long as other environmental conditions are suitable, such as appropriate water temperature.

Table 5. Major water storage facilities and irrigation diversions in the Deschutes River.

Facility	Owner	Operator	Impediment to lamprey passage (Y/N/Potential/Likely)		Pacific lamprey present?
			Adult	Juvenile	
Deschutes River Project					
Storage Facilities					
Crane Prairie Dam and Reservoir	United States	Central Oregon Irrigation District (transferred works)	Yes	Unknown	Unknown but not likely
Wickiup Dam and Reservoir	United States	North Unit Irrigation District (transferred works, 1955)	Yes	Unknown	Unknown but not likely
Haystack Dam and Reservoir	United States	North Unit Irrigation District (transferred works)	Yes	Unknown	Unknown but not likely
Diversions and Distribution Facilities					
Arnold Diversion Dam and Arnold Canal	Arnold ID	Arnold ID	Yes	Unknown	Unknown but not likely

Facility	Owner	Operator	Impediment to lamprey passage (Y/N/Potential/Likely)		Pacific lamprey
Central Oregon Diversion Dam and Central Oregon Canal	Central Oregon ID	Central Oregon ID	Yes	Unknown	Unknown but not likely
North Canal Dam and Related Diversion Facilities North Unit Main Canal North Unit Main Canal North Canal (Pilot Butte Canal) Swalley Canal	Private BOR Private Private	NUID NUID SID	Yes		Unknown but not likely
Crooked River Pumping Plant	Private	Private			Unknown but not likely
Crooked River Project					
Storage Facilities					
Arthur R. Bowman Dam and Prineville Reservoir	United States	Ochoco Irrigation District (transferred works) (U.S. contracts with OID for O&M)	Yes	Unknown	Unknown but not likely
Ochoco Dam and Reservoir	Ochoco Irrigation District	Ochoco Irrigation District	Yes	Unknown	Unknown but not likely
Diversions and Distribution Facilities					
Crooked River Feed Canal, Distribution Canal, and Pumping Plants	United States	United States			Unknown but not likely

Facility	Owner	Operator	Impediment to lamprey passage (Y/N/Potential/Likely)		Pacific lamprey
Ochoco Main Canal, Rye Grass Canal, and other distribution canals	Ochoco Irrigation District	Ochoco Irrigation District			Unknown but not likely
Crooked River Project Extension					Unknown but not likely
Wapinitia Project, White River Basin					
Storage Facilities					
Wasco Dam and Clear Lake	United States	Juniper Flat District Improvement Company (transferred works)	Project occurs upstream of impassable barrier	Unknown	Unknown but not likely
Diversions and Distribution Facilities					
Juniper Flat District Improvement Company (JFDIC) Ditch	Juniper Flat District Improvement Company	Juniper Flat District Improvement Company	Not likely	Not likely	Unknown but not likely
Non-Reclamation Projects					
Pelton-Round Butte Project					
Pelton Re-regulating Dam	Portland General Electric	Portland General Electric	Yes	Unknown	Unknown
Pelton Dam	Portland General Electric	Portland General Electric	Yes	Unknown	Unknown
Round Butte Dam	Portland General Electric	Portland General Electric	Yes	Unknown	Unknown
Opal Springs Dam	Deschutes Valley Water District	Deschutes Valley Water District	Yes	Unknown	Unknown but not likely

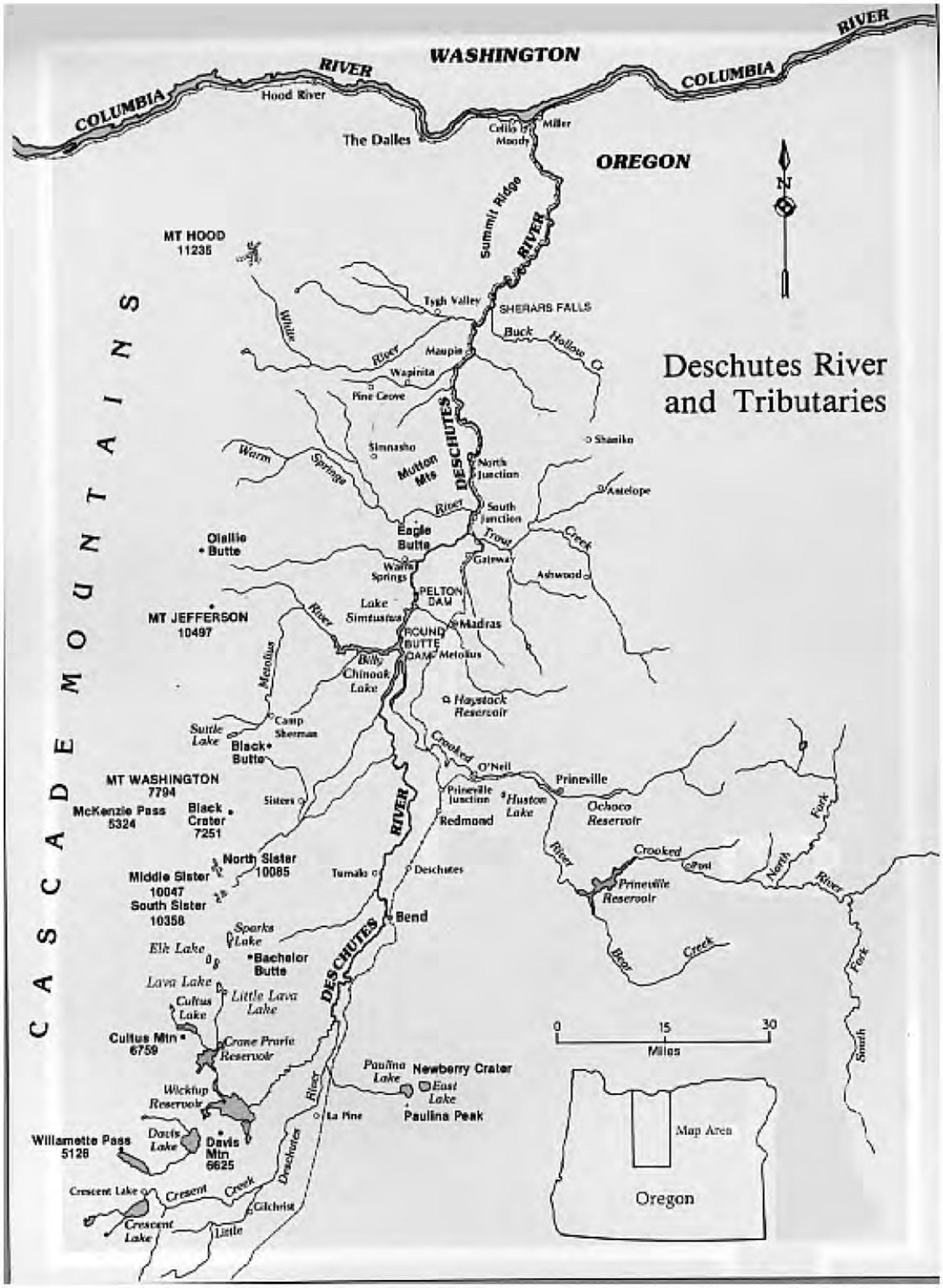

Figure 26. Map of the Deschutes River Basin. Source: http://www.flyfishusa.com/about-our-waters/deschutes-river/basin-map/desmap.html

7.2 Tualatin Project

The Bureau of Reclamation's Tualatin Project lies primarily in Washington County in the northwest part of the Willamette Basin(4th-field HUC 17090010) , west of and adjacent to the city of Portland, Oregon. It provides irrigation water to about 17,000 acres of land. Several communities and an industrial corporation are furnished untreated water for municipal and industrial use. Fish and wildlife enhancement, recreation, water quality and flood control are also important project functions. Construction of the Tualatin Project was authorized by the Congress by the Act of September 20, 1966 (80 Stat. 822, Public Law 89-596). Construction of project facilities was completed in 1978. Water stored in Henry Hagg Lake provides water to supplement the natural streamflow of the Tualatin River and help meet the increasing water requirements of the area. Water is released for normal river flow and for all project functions by the outlet tunnel and spillway outlet channel into Scoggins Creek downstream from the dam.

Principal features of the project include Scoggins Dam on Scoggins Creek that forms Henry Hagg Lake, Patton Valley Pumping Plant, Spring Hill Pumping Plant, booster pumping plants, and piped lateral distribution systems. Scoggins Creek enters the Tualatin River at RM 60.0.

The Lake Oswego Corporation dam at RM 3.4 on the Tualatin River diverts about 60 cfs of water into Lake Oswego via the Lake Oswego Canal. This privately owned structure was built about 1940. Anadromous salmonids can pass this dam and migrate upstream to suitable spawning habitat. The river behind this diversion dam up to about RM 30 is somewhat reservoir-like in that it is wide, deep, and slow moving. Below the diversion dam there is a series of riffles and pools before the river enters the Willamette River.

7.2.1 Water Storage Facilities

Scoggins Dam

Scoggins Dam is a 151-foot-high zoned earthfill structure that is 2,700 feet long. The total capacity of Henry Hagg Lake is 59,910 acre-feet (active 53,600 acre-feet). Scoggins Dam does not have fish passage facilities and is a barrier to fish passage to upper Scoggins Creek. The Scoggins Dam (Figure 27) and Henry Hagg Lake area encompasses 2,581 acres and provides 1,132 acres of water surface with 11 miles of shoreline at full pool. Henry Hagg Lake is stocked annually with rainbow trout to provide a recreational fishery. Some non-native warmwater fish species have been introduced into the lake to provide additional recreational fishing opportunities. Minimum flows are provided in Scoggins Creek and a fish trap was built below Scoggins Dam to collect the anadromous fish blocked by the dam. Steelhead were native to the Tualatin River basin, while Chinook and coho salmon were introduced.

The gated spillway at Scoggins Dam permits effective use of the top 20,300 acre-feet of reservoir space for flood control. Henry Hagg Lake has 30,000 acre-feet of capacity assigned to flood control and can completely regulate a flood of the size which occurs about once in 50 years at the damsite.

Scoggins Dam and Henry Hagg Lake were initially operated and maintained by the Bureau of Reclamation. Responsibility for the operation and maintenance of Scoggins Dam was transferred to the Tualatin Valley Irrigation District in September 1983. Scoggins Dam and part of the reservoir is shown in Figure 27.

Figure 27. Scoggins Dam and Reservoir.

7.2.2 Water Diversion Facilities

Patton Valley Pumping Plant and Distribution System

Irrigation water released at the dam is pumped into the distribution system by two downstream pumping plants. Patton Valley Pumping Plant was constructed on the right bank of Scoggins Creek about 2.5 miles downstream from the dam. This is an outdoor plant with five vertical shaft turbine pumps having a combined capacity of 38.7 cubic feet per second. A woven-wire screen with openings not exceeding 3/32 inch and new seals were fish protection improvements that became operational in 2001. These improvements meet NOAA Fisheries and ODFW criteriato screen juvenile fish from water delivery systems. In addition to this, Reclamation and TVID have committed to operating PVPP at a capacity of 11 cfs or less. Water from the five pumping units is delivered a short distance to a 19,118 cubic-foot capacity steel regulating tank by a 30-inch outside diameter steel discharge line. Some 3.5 miles of buried, gravity-fed pipeline serve about 1,900 acres of land.

Spring Hill Pumping Plant and Distribution System

The Spring Hill Pumping Plant, a cooperative venture between the Bureau of Reclamation and the city of Hillsboro, is located on the right bank of the Tualatin River at RM 56 about 9 miles downstream from the dam and 3 miles south of Forest Grove, Oregon. Nine irrigation pumps with a combined capacity of 148.2 cubic feet per second deliver water through a 60-inch-diameter concrete pipe discharge line to an 84,900 cubic foot capacity buried concrete regulating tank. The 82.5-mile-long buried pressure pipeline distribution system ranges in size from 54 to 6 inches in diameter and serves 10,300 acres at the rate of 0.014 cubic feet per second for each acre at a total dynamic head of 127 feet. About 65 miles are asbestos-cement pipe, and the remaining 17.5 miles are reinforced concrete pipe. In addition to the service provided by the Spring Hill and Patton Valley Pumping Plants, 4,800 acres are served by direct pumping of released storage water from Scoggins Creek and the Tualatin River.

The city of Hillsboro presently owns and operates three pumping units installed in the Spring Hill Pumping Plant, with a combined capacity of 32.2 cubic feet per second that supplies water to itself and the cities of Beaverton and Forest Grove.

The Patton Valley and Spring Hill Pumping Plants and related irrigation facilities are operated and maintained by the Tualatin Valley Irrigation District.

7.2.3 Pacific Lamprey Issues in the Tualatin River Basin

Pacific lamprey are native to the Tualatin River, an important tributary to the Willamette River, and have the potential to be present in lower Scoggins Creek below Scoggins Dam.

Little information is available regarding historic abundance and distribution of Pacific lamprey in the Tualatin Basin, although recent studies suggest that lamprey are present throughout the basin (Baker and Keefe 2003). Pacific lamprey were historically abundant in the Willamette River as indicated by estimated counts at Willamette Falls downstream from the mouth of the Tualatin River. Pacific lamprey numbered in the hundreds of thousands at Willamette Falls in the 1940s, but their numbers have declined substantially in recent years, as they have throughout the Columbia River basin.

The overall abundance and distribution of Pacific lamprey in the Tualatin River Subbasin is not known. The abundance of Pacific lamprey has declined substantially throughout the Columbia River Basin and have only relatively recently been the focus of systematic surveys, and data on historic lamprey abundance and distribution is limited. Juvenile lamprey have been documented in several recent surveys in the basin, but in some cases it was uncertain whether they were Pacific or Western brook lamprey. One lamprey ammocete was observed during a redd survey in Scoggins Creek below the dam (White 2003a, cited in Baker and Keefe 2003). Juvenile lamprey have been documented in several tributaries of the Tualatin

River, such as Fanno Creek (tributary to the lower Tualatin River), and Chicken Creek (RM 25.9). These sites are well downstream from Reclamation facilities in the Tualatin River. Unidentified juvenile lamprey species were found in Gales Creek (Leader and Hughes 2000, cited in Baker and Keefe 2003), but it is uncertain whether these fish were Pacific lamprey or Western brook lamprey. Gales Creek is just upstream from the Spring Hill Pumping Plant.

Since Scoggins Dam does not have fish passage facilities, anadromous salmonids have access to only lower Scoggins Creek below the dam. This is likely also the upstream extent of Pacific lamprey distribution. The habitat in upper Scoggins Creek, Sain, and Tanner creeks is described as being limited by low seasonal flows, lack of spawning habitat, degraded water quality, and unsuitable temperatures that would affect fisheries resources (White 2002a, cited in Baker and Keefe 2003). Since the habitat conditions upstream of Scoggins Dam are considered marginal for fisheries resources at this time, it is not likely that providing passage for Pacific lamprey in the form of a LPS or LPS would provide much benefit to the population, and efforts and resources to restore population abundance would be better spent addressing and improving conditions downstream.

Scoggins Creek downstream from the dam has been listed as spawning and rearing habitat for steelhead, the main Tualatin River downstream from the mouth of Scoggins Creek has been listed as rearing and migration habitat, and the river downstream from about Dairy Creek has been listed as migration habitat.[4] Although some anecdotal reports suggest that some steelhead spawning has occurred in lower Scoggins Creek, the habitat there has been described as limiting or restricting successful salmonid reproduction (White 2002a, cited in Baker and Keefe 2003).

Since Pacific lamprey likely occurred historically wherever Pacific salmonids occurred (Simpson and Wallace 1978), and if steelhead do use lower Scoggins Creek for spawning and rearing, Pacific lamprey might do so as well. However, habitat conditions in lower Scoggins Creek are described as being marginal for steelhead at this time, and juvenile steelhead rearing has not been documented in Scoggins Creek (Reclamation 2009).

Providing passage at Scoggins Dam would allow salmon and steelhead that successfully migrated to lower Scoggins Creek access to tributaries upstream of Hagg Lake that were available historically. Although providing access to habitats upstream of passage barriers would be considered a benefit to anadromous species in many systems, recent surveys of Scoggins, Sain, and Tanner Creeks upstream of Henry Hagg Lake indicate that seasonal low flows, limited habitat diversity, lack of spawning habitat, degraded water quality, and unsuitable temperatures would be limiting factors for salmon and steelhead survival and reproduction, and likely Pacific lamprey as well, which spend up to seven years rearing in

[4] StreamNet Interactive Mapper 2010 at http://map.streamnet.org/website/bluesnetmapper/viewer.htm.

silty-sandy substrates before transforming and migrating.

A bigger benefit for anadromous fish populations from a biological perspective might be achieved by restoring habitat elsewhere in the basin, where data indicate that habitat may be suitable for increasing populations of target species.

Patton Valley Pumping Plant is screened to NOAA Fisheries criteria, which should protect adult and juvenile Pacific lamprey.

Table 6. Major water storage facilities and irrigation diversions of the Tualatin Project.

Facility	Owner	Operator	Impediment to lamprey passage (Y/N/Potential/Likely		Pacific lamprey present?
			Adult	Juvenile	
Tualatin Project					
Storage Facilities					
Scoggins Dam	United States	O&M performed by Tualatin Valley Irrigation District	Yes	Unknown	Historically present in the basin
Diversion Facilities					
Patton Valley Pumping Plant and Distribution System and fish screens	United States	Tualatin Valley Irrigation District	Potential		
Spring Hill Pumping Plant and Distribution System	United States	Tualatin Valley Irrigation District and Joint Water Commission	Potential		
Lake Oswego Diversion Dam (Privately owned facility)	Lake Oswego Corporation	Lake Oswego Corporation			

7.3 Snake River Basin

Reclamation owns and operates a number of projects upstream of the Hells Canyon Complex on the Snake River. These projects are not described in detail as the Hells Canyon dam is the uppermost limit of current distribution of Pacific lamprey (USFWS 2010). If restoration efforts above Hells Canyon were ever proposed and implemented, those projects would be assessed at that time.

In subbasins of the Snake River downstream from the Hells Canyon dam, Reclamation owns the Lewiston Orchards Project. This project has not been assessed for effects to Pacific lamprey, but a brief description of the project is provided here.

7.3.1 Lewiston Orchards Project

This project is located in northern Idaho on a bench south of the Clearwater River near the City of Lewiston. The Project collects water from the Craig Mountain drainage area that is partially located on the Nez Perce Reservation. Project features consist of three storage reservoirs (Soldiers Meadow, Lake Waha, and Reservoir A), four smaller diversion structures (Captain John, West Fork Sweetwater, Webb, and Sweetwater), one pump in Lake Waha, and associated canals. Webb diversion dam, Webb Canal, Reservoir A and some portions of Sweetwater Canal are located within the Tribe's Reservation boundary. The rest of the Project affects streams that flow into and through the Nez Perce Reservation (see Figure, "Lewiston Orchards Project Map").

Project facilities are located in three basins: Captain John Creek, Sweetwater Creek, and Lindsay Creek. The Captain John Creek Basin is involved only via a small diversion dam in its headwaters, from which water is diverted each spring to the Sweetwater Basin. With the exception of the Captain John Creek diversion, water supply for the Project is collected from the Sweetwater Creek Basin (including Sweetwater Creek and its main tributary, Webb Creek), where Soldiers Meadow Reservoir, Lake Waha, and the diversion dams are located. From the Sweetwater Basin, water is diverted to Reservoir A in the Lindsay Creek basin.

Referring to Figure 1-1, Project facilities and system configuration are further described below.

Captain John Creek Basin Elements: The Captain John diversion is located in a small basin at the headwaters of Captain John Creek. Water from this diversion is conveyed via canal and excavated channel to the watershed of Webb Creek, where it is stored in Soldiers Meadow Reservoir.

Sweetwater Basin—Webb Creek Elements: Water from the headwaters of Webb Creek (and the Captain John diversion) is stored in Soldiers Meadow Reservoir. From the reservoir, water is released into the natural Webb Creek channel, from which (approximately 6 miles downstream of the dam) it is diverted at the Webb Creek diversion dam and conveyed via the Webb Canal to East Fork Sweetwater Creek, and ultimately to the mainstem of Sweetwater Creek, where it is diverted into the Sweetwater Canal via the Sweetwater Diversion Dam.

Sweetwater Basin—Sweetwater Creek Elements: Water from West Fork Sweetwater Creek is diverted via West Fork diversion dam and the Waha Feeder Canal into Lake Waha, a natural lake with no natural outlet. Water stored in Lake Waha is pumped from the lake and conveyed to the mainstem of Sweetwater Creek via a pipeline and a tributary of West Fork Sweetwater Creek known as Forsman Draw. On the mainstem of Sweetwater Creek, the Sweetwater diversion dam feeds water to the Sweetwater Canal, which conveys the water supply out of the Sweetwater Basin into the Lindsay Basin.

☐

Lindsay Creek Basin Elements: Water from the Sweetwater Basin (via the Sweetwater Canal) is stored in Reservoir A. From this reservoir, water is supplied directly to the LOID service area via pipeline and the Project distribution system.

8.0 SUMMARY

This report serves to document Reclamation’s assessment of projects in the Columbia River Basin that may affect Pacific lamprey, with a focus on the Yakima and Umatilla basins. The following are summaries of recommendations for either further study or actions that may be taken to reduce effects on Pacific lamprey in these basins.

Table 7 summarizes Yakima River Basin projects evaluated in this assessment showing location, ownership and operation responsibilities, and lamprey issues.

Table 7. Yakima River basin projects evaluated in this assessment.

		Dam		Fish Facilities		
Location, River Mile (RM)	**Project**	**Owner**	**Operator**	**Owner**	**Operator**	**Pacific Lamprey Effects Summary**
Yakima RM18	Horn Rapids Wanawish) Diversion Dam	Columbia Irrigation District	Columbia Irrigation District	Reclamation	Reclamation	Furthest downstream structure on Yakima River. Not absolute barrier to upstream adult migration, partial barrier likely. Rotating drum screens, juvenile entrainment may be possible.
Yakima RM47.1	Prosser Diversion Dam	Reclamation	Reclamation	Reclamation	Reclamation	Likely partial barrier to adult migration. Canals screened by rotating drum screens, but juvenile entrainment may be possible.
Yakima RM103.8	Sunnyside Diversion Dam	Reclamation	Sunnyside Valley Irrigation District	Reclamation	Reclamation	Unknown if adults pass dam. May be barrier to adult migration. Rotating drum screens may allow juvenile entrainment, Western brook juvenile lamprey observed in canal.
Yakima RM106.6	Wapato Diversion	Bureau of Indian Affairs	Bureau of Indian Affairs	Reclamation	Bureau of Indian Affairs by contract	Large diversion (2,000 cfs), may be barrier to upstream migration, potential for significant entrainment issue if screens not effective.
Yakima RM127.9	Roza Diversion Dam	Reclamation	Reclamation	Reclamation screens, YN fish trap facility	Reclamation screens, YN fish trap facility	Not known if Pacific lamprey present, potential migration barrier and entrainment issues. Potential for guiding lamprey to fish trapping facility for data collection.

Location, River Mile (RM)	Project	Dam		Fish Facilities		Pacific Lamprey Effects Summary
		Owner	Operator	Owner	Operator	
Yakima RM161.3	Town Diversion Dam	Town Ditch Company	Town Ditch Company	Reclamation	Reclamation	Low dam, potential for migration inhibition, likely not complete barrier. Entrainment possibly an issue. High in basin, presence of Pacific lamprey unknown.
Yakima RM202.5	Easton Diversion Dam	Reclamation	Kittitas Reclamation District	Reclamation	Reclamation day-to-day O&M to KRD	Presence of Pacific lamprey not known, high in basin, potential for migration barrier if adults move up to it. Potential entrainment if juveniles present.
Naches RM3.6	Naches-Cowiche Diversion Dam	City of Yakima	City of Yakima	BPA and Reclamation	Reclamation and Washington State	Unknown if Pacific lamprey current or historically, small diversion but could potentially be a barrier to migration and potential juvenile entrainment
Naches RM9.4	Gleed Diversion Dam	Gleed Canal Company	Gleed Canal Company	Reclamation	Reclamation	Unknown if lamprey present, small push-up style dam does not block entire river, low potential for lamprey issues.
Naches RM17.1	Wapatox Diversion Dam	Reclamation	Reclamation	Reclamation	Reclamation	Presence of lamprey unknown, Diverts 130 cfs, returns 80 cfs. Potential passage obstacle. Wedgewire V-screens, potential entrianment. Juvenile lamprey (likely Western Brook) have been observed in canal.

Location, River Mile (RM)	Project	Dam Owner	Dam Operator	Fish Facilities Owner	Fish Facilities Operator	Pacific Lamprey Effects Summary
Tieton RM14.2	Yakima-Tieton Diversion Dam	Reclamation	Yakima-Tieton Irrigation District	Reclamation	Reclamation	Unknown if Pacific lamprey present. Potential passage barrier. Flat plate self-cleaning screen could harm juveniles (if present) if impinged.
Naches RM18.4	Naches Selah Diversion Dam	Naches Selah Irrigation District	Naches Selah Irrigation District	Reclamation	Reclamation	Unknown if lamprey present. Small push-up dam likely not passage barrier. Excess flow is diverted and returned, possible entrainment of juveniles, but some returned with flow.
Cle Ellum RM8.2	Cle Ellum Dam	Reclamation	Reclamation	Reclamation	Reclamation	Possible lamprey habitat above dam, currently unoccupied.
Kachess RM1	Kachess Dam	Reclamation	Reclamation	None	None	Lamprey not currently present, possible restoration opportunities.
Yakima RM214.5	Keechelus Dam	Reclamation	Reclamation	None	None	High in river basin, presence of Pacific lamprey not known.
Tieton RM21.3	Tieton Dam	Reclamation	Reclamation	None	None	High in river basin, presence of Pacific lamprey not known.
Tieton RM7.3	Clear Creek Dam	Reclamation	Reclamation	Reclamation	Reclamation	High in river basin, presence of Pacific lamprey not known.

Location, River Mile (RM)	Project	Dam Owner	Dam Operator	Fish Facilities Owner	Fish Facilities Operator	Pacific Lamprey Effects Summary
Bumping RM17.0	Bumping Lake Dam	Reclamation	Reclamation	None	None	High in river basin, presence of Pacific lamprey not known.

Yakima River Basin recommendations are influenced by the low populations of Pacific lamprey in the basin, which focuses on getting adults into the basin as a priority. Recommendations for the Yakima River Basin are:

- Gather information, via support of the FWS radiotelemetry study and other data collection to determine passage routes and site specific data needed to plan adult passage.
- Populations are very low and there may be a need to supplement the study with individuals from the Columbia River. This may require overwintering capability; opportunity for this at Reclamation facilities should be explored.
- Support and assist Yakama Nation's translocation and propogation efforts through facilities where opportunity exists, and funding support.
- Consider adult lamprey passage structures where feasible and where data indicates the need, with focus in the lower river. Use results from radiotelemetry study to prioritize and design structures.
- Conduct surveys behind fish screens at Reclamation projects, and use data to prioritize locations for further study to quantify entrainment or effect on juveniles and determine mechanisms of effects.
- Support ongoing work to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey where determined appropriate.

Table 8 summarizes Umatilla River Basin projects evaluated in this assessment showing location, ownership and operation responsibilities, and lamprey issues.

Table 8. Umatilla River basin diversion dams evaluated in this assessment.

		Dam		Fish Facilities		
Location, River Mile (RM)	**Project**	**Owner**	**Operator**	**Owner**	**Operator**	**Pacific Lamprey Effects Summary**
Umatilla RM 3	Three Mile Falls Diversion Dam	Reclamation	West Extension Irrigation District	BPA	CTUIR	Lamprey Passage Structure installed, need to monitor. Possible juvenile entrainment, drum screens.
Umatilla RM 15.5	Maxwell Diversion Dam	Reclamation	Hermiston Irrigation District	BPA	Westland Irrigation District	Low diversion with flat plate added to enhance lamprey passage. Possible juvenile entrainment, 1 mile of canal between diversion and fish screens.
Umatilla RM 24	Dillon Diversion Dam	Private	Owner			Non-Reclamation.
Umatilla RM 28	Westland Diversion Dam	Westland Irrigation District	Westland Irrigation District	BPA	Westland Irrigation District	Possible adult passage and juvenile entrainment issues.
Umatilla RM 29	Feed Canal Diversion Dam	Reclamation	Hermiston Irrigation District	Reclamation	Reclamation and CTUIR	Diversion with Lamprey Passage Structure installed.
Umatilla RM 33	Stanfield Diversion Dam	Stanfield Irrigation District	Stanfield Irrigation District	BPA	Westland Irrigation District	Possible adult passage and juvenile entrainment issues.
McKay Creek RM 6	McKay Dam	Reclamation	Reclamati on	Reclamation	Reclamation	High storage dam with no fish passage facilities, no lamprey above dam.

The Umatilla River Basin has successful translocation populations and some progress in adult passage capability. The priority in this basin is on juvenile protection issues and monitoring adults movements as needed. Recommendations include:

- Monitor effectiveness of adult lamprey passage at Reclamation facilities
- Study migration and timing of juveniles in system
- Continue and expand surveys behind fish screens at Reclamation projects, and use data to prioritize locations for further study to quantify entrainment or effect on juveniles and determine mechanisms of effects.
- Support ongoing work to investigate the effectiveness of current fish screens at protecting lamprey, develop techniques to guide lamprey away from diversions, and develop methods or mechanisms to protect juvenile lamprey.

As recommended by this Assessment, Reclamation is committed to coordinating and collaborating with the Tribes to further assess the issues of effects on Pacific lamprey in the Columbia River basins, further the knowledge of Reclamation project's effects on Pacific lamprey, and explore options to implement passage and/or protection measures as informed by these studies.

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APPENDIX B

Presence of Early Life-Stages of Pacific Lamprey Above and Below Water Intake Screens in Bureau of Reclamation Canals in the Umatilla River Basin

RECLAMATION
Managing Water in the West

Technical Memorandum No. 86-68290-12-03

Presence of Early Life-Stages of Pacific Lamprey Above and Below Water Intake Screens in Bureau of Reclamation Canals in the Umatilla River Basin

U.S. Department of the Interior
Bureau of Reclamation

March 2012

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

This study was initiated under one of Reclamation's commitments in the 2008 Columbia River Fish Accords. The purpose of this study is to help Reclamation understand the potential effects of Reclamation projects on Pacific lamprey.

Cover Photograph: Pacific lamprey sampling in West Extension Canal, Umatilla River Basin (Insert: Pacific lamprey)

Technical Memorandum No. 86-68290-12-03

Presence of Early Life-Stages of Pacific Lamprey Above and Below Water Intake Screens in Bureau of Reclamation Canals in the Umatilla River Basin

Umatilla River Basin, Oregon

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Executive Summary

Pacific lamprey (*Lampetra tridentata*) are a resource of great significance and importance to Tribes in the Pacific Northwest. In 2008, Reclamation entered into a Memorandum of Agreement with Columbia River Basin states and Tribes, known as the Fish Accords, which are tied to the Federal Columbia River Power System Biological Opinion. In the Fish Accords, Reclamation committed to assessing Reclamation project effects on Pacific Lamprey and working with Tribes on Pacific lamprey issues. Under one of these commitments, Reclamation worked with the Confederated Tribes of the Umatilla Indain Reservation to systematically sample Reclamation canals in the Umatilla River Basin shortly after they were dewatered to estimate the extent of juvenile lamprey entrainment through the fish screens. Feed, Maxwell, and West Extension canals were all sampled by backpack electrofisher and other methods to search for stranded lamprey both in front of and behind the screens, including down the length of the canals. In this first year of systematic sampling, a total of 14 Pacific lamprey were collected: one in Feed Canal, zero in Maxwell Canal, and 13 in West Extension Canal. All but one lamprey were collected upstream of the screening facilities, and the other was collected within the drum screen (after de-watering and lifting of the screen) at West Extension Canal Facilities. No lamprey were found beyond the screen structures at any of the facilities.

Introduction

Pacific lamprey (*Lampetra tridentata*) are a resource of great significance and importance to Tribes in the Pacific Northwest, serving both as a traditional and ceremonial food source, and as medicine for tribal members (Close 2002). Pacific lamprey also provide numerous ecologically important benefits to aquatic ecosystems, such as a food source for juvenile salmon, birds, and mammals, and historically were a source of marine-derived nutrients that helped sustain aquatic and terrestrial ecosystems (Lewis 2009). Pacific lamprey show declining abundances throughout much of their native range, including the Umatilla River Drainage, OR. In recent years, the population of adult Pacific lamprey has declined sharply. Record low returns were seen in 2010; though numbers have rebounded somewhat in 2011 they are still much below historical returns.

Screens developed at the head of instream water diversions (i.e., canals) in the Umatilla River Basin were not designed to exclude ammocoete (larval life-stage, pre eye development) or macropthalmia (juvenile eyed life-stage) Pacific lamprey, but generally to prevent entrainment of more efficient and powerful swimming salmonids (Mesa et al. 1999; CRITFC 2011; Sutphin and Hueth 2010). However, early life-stages of Pacific lamprey are likely to be exposed to screened (and unscreened) diversions because they generally migrate downstream either as ammocoetes dislodged from sediments by high-flow events, or as outmigrating macropthalmia. At these life stages, they have not yet developed strong swimming abilities and their movements are primarily dictated by flow (Mesa et al. 1999; Kostow 2002). For example, downstream migration of early life-stages of lamprey in the Umatilla River generally occurs from winter to early spring, the same time period when some of Bureau of Reclamation's (Reclamation) Umatilla Basin Project canals, Feed Canal in particular, are taking water for irrigational needs (Kostow 2002; Chet Sater Pers. Comm.. 2011). Therefore, water diversions, even if screened, may result in entrainment loss, as lamprey may exhibit the ability to pass some fish screens (Long 1985; Kostow 2002). This can be further problematic for lamprey, because canal de-watering can result in minimal or no flow conditions which ultimately create poor water quality (i.e., hypoxic and extreme temperature conditions) and habitat conditions that can ultimately be lethal to entrained lamprey (BioAnalysts 2000; Close 2002).

Reclamation works with the Yakama Nation (YN) and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) to better understand effects of Reclamation projects to Pacific lamprey and investigate possible solutions. The Columbia River Fish Accords, which are linked to the Federal Columbia River Power System (FCRPS) Biological Opinion, were entered into in May 2008 by Reclamation and three of the four Columbia River Treaty Tribes (YN, CTUIR, and Warm Springs). The Fish Accords identify specific commitments for Reclamation including:

1. Beginning in 2008, and concluding in 2010, Reclamation will conduct a study, in consultation with the Tribes, to identify all Reclamation projects in the Columbia Basin that may affect lamprey. The study will also investigate potential effects of Reclamation facilities on adult and juvenile lamprey, and where appropriate, make recommendations for either further study or for actions that may be taken to reduce effects on lamprey. The priority focus of the study will be the Umatilla and Yakima projects and related facilities.
2. Beginning in 2008, Reclamation and the Tribes will jointly develop a lamprey implementation plan for Reclamation projects as informed by the study above, the tribal draft restoration plan, and other available information. The plan will include priority actions and identification of authority and funding issues. It will be updated annually based on the most recent information. Reclamation will seek to implement recommended actions from the implementation plan (2008

Columbia Basin Fish Accords, Memorandum of Agreement between the Three Treaty Tribes and FCRPS Action Agencies, May 2008).

Reclamation completed an assessment of Reclamation projects in 2010. One of the recommendations for the Umatilla basin was: "continued sampling and/or entrainment studies of project canals should be done to help determine the extent of entrainment and screen mortality issues, as well as prioritize projects for further study and to outline actions to reduce effects to Pacific lamprey. These larval lamprey surveys should be completed behind the fish screens at Three Miles Falls Dam, Feed Canal, and Maxwell diversions, with the outcome of those surveys setting priority for further study to determine extent and mechanism of entrainment, leading to identification of possible actions to address entrainment." Previous sampling by CTUIR indicated the presence of lamprey in some irrigation canals in the Umatilla River Basin, indicating the need for more systematic sampling to understand the extent of lamprey entrainment (CRITFC 2011).

The primary objective of this research was to complete short-term data collection efforts to estimate entrainment loss (i.e., loss into canals and through screens) of early life-stages (larval – juvenile) of Pacific lampreys from the mainstem Umatilla River into regional Reclamation canals: Feed, Maxwell, and West Extension Canals, shortly (< 7 d) after dewatering.

Methods

Electrofishing Methodology

Two backpack model ABP-2 electrofishers (Engineering Technical Services, Madison, WI) were used to assess Pacific lamprey presence/absence up- and downstream of Reclamation canal screening facilities in Reclamation's Feed, Maxwell, and West Extension Canals (Umatilla River Basin, OR). During general operation the electrofisher unit was set-up to deliver three pulses per second at 25% duty cycle to provide stimulation and electro-taxis, forcing lamprey to evacuate their burrow (in soft sediment). Once a swimming lamprey was observed, 30 pulses per second was initiated to cause brief tetanus until the lamprey could be netted. Electrofishing methods followed those initially developed by Hintz (1993), and employed by CTUIR (Aaron Jackson Pers. Comm. 2011). Within each sample location multiple sites (~7.5 m^2 sections at Feed Canal and majority of pre-screen in Maxwell Canal, and ~15 m^2 sections in the majority of post-screen at Maxwell and all of West Extension Canal) were sampled. Additionally, extensive efforts intended to cover larger reaches just up- and downstream of each canal's fish screen were completed. Greater effort was concentrated immediately up- and downstream of the screens based on the assumption that, if entrained and restricted further passage by the screen, higher densities of lamprey would reside in these locations. Each 7.5 or 15 m^2 sample site was assessed in a single 11 min pass, generally moving very gradually (~ 45 - 90 sec/m^2) in pairs of two (electrofisher operator and netter) in an upstream direction (Figure 1). As a result of the small quantities of lamprey collected, sampling effort (area per unit time) was amplified starting after the screen at Maxwell Canal (second of three canals sampled) to increase total area sampled in an effort to increase the likelihood of encountering entrained lamprey. Before applying changes in sampling methodology (from 7.5 to 15 m^2 plots), proposed changes were coordinated by Reclamation (Sue Camp, Pacific Northwest Regional Office) with CTUIR (Aaron Jackson, CTUIR Fisheries) personnel.

Figure 1. Bureau of Reclamation and Confederated Tribe of the Umatilla Indian Reservation employees electrofishing Feed Canal (location 3, sample sites 1 and 2), below the fish screens to determine presence/absence of early life-stages (ammocoete or macropthalmia) of Pacific lamprey (*Lampetra tridentata*).

Sample locations were selected systematically, but selection process differed slightly as a function of canal characteristics (see *Sample Sites* below). To assist with sample location selection, Reclamation and, in some cases CTUIR personnel, accessed the entire length of canals via canal roads to examine sampling conditions and available habitat. Sample sites within each location were not selected randomly, because we attempted to sample sites that contained significant amounts of the preferred habitat type (type-I habitat, soft small grain sediments) for burrowing ammocoete/macropthalmia lamprey. At most sample locations, key habitat characteristics (i.e., approximate water depth, substrate type and depth, vegetation, etc.) were noted, water quality (temperature and conductivity; YSI85 multimeter, Yellow Springs, OH.) was measured, and following each sample effort GPS waypoints (Garmin Oregon 400T, Olathe, KS) were collected. Dissolved oxygen levels (mg/L, YSI multimeter) were collected in Maxwell and West Extension Canals, but not in Feed Canal. After collection, lamprey were anaesthetized using a buffered solution of tricaine methansulfonate, identified to life stage (ammocoete or macropthalmia) measured for total length (mm), weighed (g), briefly recovered in fresh water, and returned to the Umatilla River. Macropthalmia were differentiated from ammocoete lamprey by the presence of eyes.

Sample Locations and Sites

Feed Canal

Lamprey sampling was completed at Feed Canal on April 27 and 28, 2011. De-watering of the canal was initiated on April 20, 2011. Due to limited area upstream of the Feed Canal screening facilities, and downstream of the headworks on the Umatilla River, we completed two sampling efforts of increased duration (location 1, sites 7 (95 total sampling minutes) and 8 (61 total sampling minutes); Appendix A, Table 1a) in an attempt to have similar sampling efforts (unit area and time) upstream and downstream of the screening facilities (Figure 2). This effort also allowed us to cover the entire area of the pre-screen section of the canal for lamprey salvage purposes. Also, given the significant length of unlined canal, we attempted to select sample locations concentrated near the screening facilities (Figure 3) and gradually increase distances between sites downstream as the canal approached Cold Springs Reservoir. However, because the canal was de-watered and much of the canal between downtown Hermiston, OR (Highway 395 crossing) and South Howards Road Bridge provided no submersed habitat, we did not sample within this stretch. Also we did not sample any locations upstream of Cold River Springs Reservoir to the South Howards Road Bridge because water depths (> 1.5 m) precluded us from using our sampling equipment. As a means to cover all available habitat, horizontally across the canal, sites were often sampled in parallel (see Figure 1). Sample site selection and electrofishing at Feed Canal was done with the aid of CTUIR employees.

Figure 2. Confederated Tribe of the Umatilla Indian Reservation employees electrofishing Feed Canal (location 1, sample site 1) upstream of the canal fish screening facilities to determine presence/absence of juvenile Pacific lamprey (*Lampetra tridentata*).

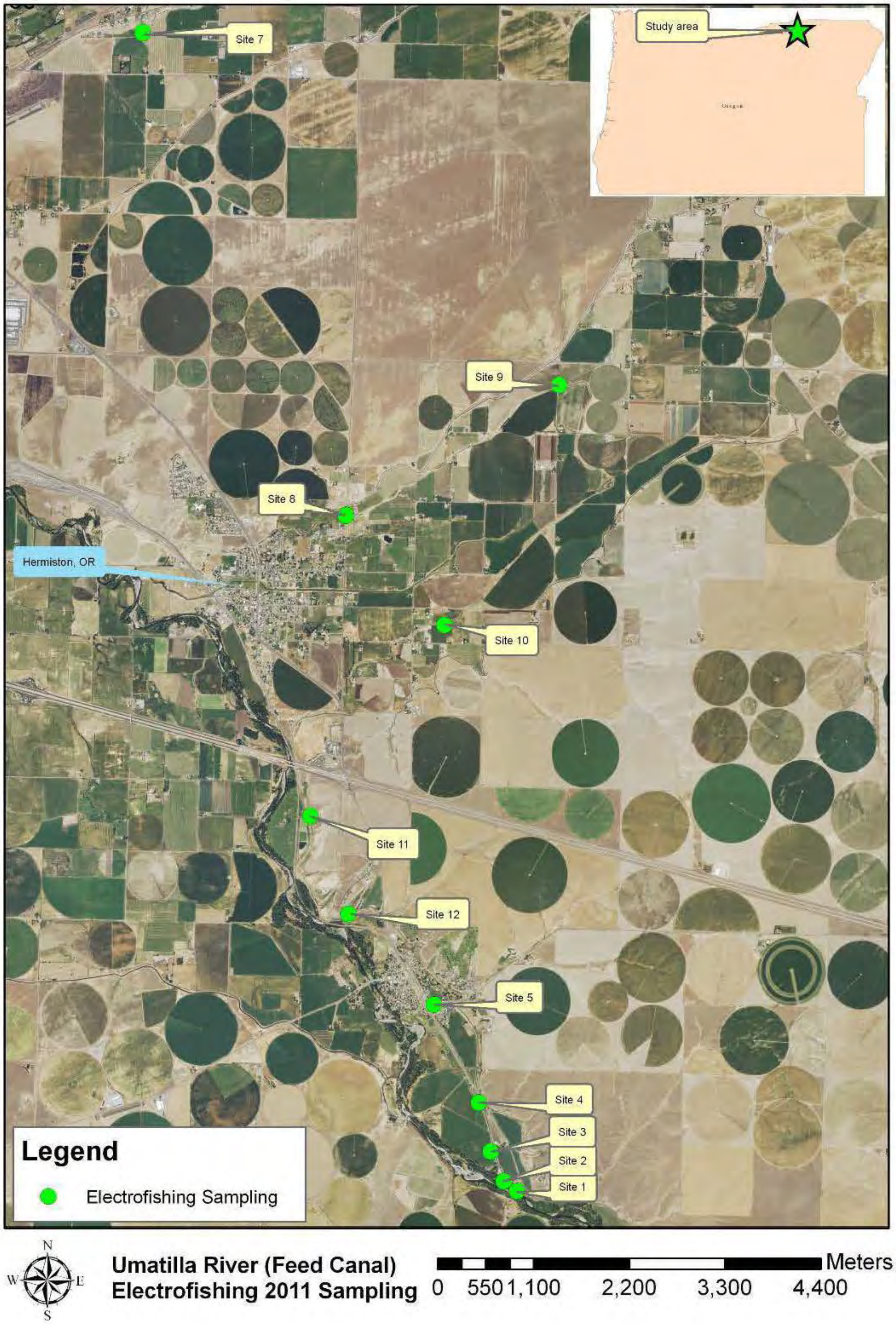

Figure 3. Electrofishing sample sites on Reclamation's Feed Canal. Locations 1-5 were sampled on day 1 (April 27, 2011) and locations 7-12 were sampled on day 2 (April 28, 2011). Locations 1 and 2 were upstream of the Feed Canal fish screening structure, but downstream of the Umatilla River confluence. Locations 3 – 12 were downstream of the fish screening structure.

Maxwell Canal

Lamprey sampling was completed at Maxwell Canal on October 18 and 19, 2011. De-watering of the canal was initiated on October 14, 2011. Twelve locations, at near equally spaced ~ 0.19 km intervals, from the headworks to fish screen (total distance = 2.44 km), were sampled above the screen in Maxwell canal. Within each above screen location, two ~ 7.5 m sample sites were sampled at a rate of 11 min each. Typically, because of the narrow width of the canal after dewatering (Figure 4), sites were sampled in series (with one site beginning at the endpoint of the other) rather than in parallel. However, because canal wet-width was narrow, this allowed for sampling the majority of available habitat horizontally across the width of the canal. Additionally, two 55 m^2 plots, spanning a sample time of 32 min each, were sampled upstream of the apron leading to the fish screens (Figure 5). The majority of Maxwell Canal concrete apron area immediately upstream of the screens (Figure 6) was either dewatered or contained < 3 - 4 cm of water. Because this habitat was recently dewatered ($\leq$ 1 d) and could potentially harbor burrowed lamprey, a pitchfork was employed to work through ~15 m^2 of soft sediment. Below Maxwell Canal fish screens, the first five locations, with two sample sites at each locale, consisted of ~7.5 m^2 plots sampled over 11 min. The remaining seven locations, also with two sample sites at each locale, consisted of ~15 m^2 plots sampled over 11 min. Sample locations below the screen, from the screen to the wasteway, were spaced out at ~ 0.19 km intervals. Below the Maxwell Canal wasteway to the end of the canal, locating sample locations at 0.8 km intervals was attempted, but limited access resulted in an inability to standardize intervals between locations.

Figure 4. Reclamation biologist Zak Sutphin electrofishing Maxwell Canal in an effort to capture entrained Pacific lamprey (*Lampetra tridentata*). Biologist Sue Camp (Reclamation, PN Region) on shore recording pertinent habitat characteristics and water quality.

Figure 5. Electrofishing sample sites on Reclamation's Maxwell Canal. Locations 1 through 12 were upstream of the Maxwell Canal fish screening structure, but downstream of the Umatilla River confluence. Locations 13 - 23 were downstream of the fish screening structure.

Figure 6. Image of fish screens at Maxwell Canal (February 2011). Because there was minimal habitat containing water with depths great enough for using electrofishing equipment, a pitchfork was used to overturn soft sediment in an attempt to recover larval/juvenile Pacific lamprey (*Lampetra tridentata*).

West Extension Canal

Sampling for lamprey was completed in West Extension Canal November 2 and 3, 2011. De-watering of the canal occurred on November 1, 2011. All areas containing exposed or submersed soft sediment above the fish screen to the headworks on West Extension Canal, as well as below the screens to the stop-log channel in the post-screen bay, were sampled (Figure 7). Sampling in areas immediately up- and downstream of the fish screens (Figure 8) constituted electrofishing all locations containing submersed type-I habitat, as well as walking and visually inspecting the entire area for stranded lamprey, and working though soft sediment with a pitchfork (Figure 9).

The entire length of West Extension Canal, from the stop-log channel below the fish screens to the end of the canal (behind rest area on Highway 84, west of Boardman, OR) is concrete lined. Therefore, sampling efforts focused on areas containing preferred type-I habitat (soft sediment), which was generally observed at concrete check structures. Below the stop-log channel in the post-screen bay, sampling efforts consisted of ~15 m^2 sites over 11 min intervals. Typically, two to six sites were sampled, in end-to-end series, over three sample locations.

Figure 7. Electrofishing sample sites on Reclamation's West Extension Canal. Location 1 was upstream of the West Extension Canal fish screening structure, but downstream of the Umatilla River confluence. Locations 2-5 were downstream of the fish screening structure.

Figure 8. Reclamation Biologists Eric Best and Zachary Sutphin using electrofishing equipment to sample for Pacific lamprey (*Lampetra tridentata*) above (left image) and below (right image) fish screens in Reclamation's West Extension Canal (Reclamation; Umatilla River Basin, OR).

Figure 9. Pitch forks were often employed to sample soft, recently dewatered, habitat in an attempt to recover entrained Pacific lamprey (*Lampetra tridentata*) from both Maxwell and West Extension Canal (Reclamation; Umatilla River Basin, OR).

On occasion, one electrofisher was employed at West Extension due to safety concerns coinciding with deep (> 0.5 m) soft sediment. In addition to described sampling techniques, a ~ 1 × 1 × 2 m mass of aquatic vegetation (filamentous algae) was inspected, by hand, for lamprey (Figure 10). This technique was attempted because it was hypothesized that the limited amount of available type-I habitat in West Extension Canal could require entrained lamprey to seek non-traditional burrowing habitats (e.g., vegetation). All sample locations and sites in West Extension Canal were selected by Reclamation biologists.

Figure 10. Masses of vegetation were processed, by hand, in Reclamation's West Extension Canal (Umatilla River Basin, OR) in an effort to collect Pacific lamprey (*Lampetra tridentata*).

Results and Discussion

Over all the three Reclamation canals sampled, a total of 14 Pacific lamprey were collected: one in Feed Canal, zero in Maxwell Canal, and 13 in West Extension Canal. All but one lamprey were collected upstream of the screening facilities, and the other sampled lamprey was collected within the drum screen (after de-watering) at West Extension Canal Facilities. Of the 14 lamprey sampled, three were ammocoetes (1 from Feed, 2 from West Extension) and 11 were macropthalmia. Total sampling effort, reported as time, up- and downstream of fish screens in Feed, Maxwell, and West Extension Canals were 222 and 374 min, 363 and 264 min, and 32 and 267 min.

Feed Canal

At Feed Canal a total of 12 sample locations, 1 upstream of the Feed Canal screening facilities to the headworks on the Umatilla River and 11 downstream of the screening facilities, were sampled (see Figure 3). Total number of sample sites (7.5 m^2 plots) within each sample location ranged from one (location 6) to six (location 1; Appendix A, Table 1a). Though sampling effort as a function of time was > 150% downstream (374 min) compared to upstream (222 min) of the screening facilities, because of the large area sampled immediately upstream of the screens (Figure 11), effort as a function of area sampled was greater upstream (~ 1,700 m^2 of wetted area sampled) compared to downstream (~ 632 m^2). Across all efforts in Feed Canal, only one ammocoete Pacific lamprey (123 mm TL, 3.6 g) was sampled upstream of the screens (location 1, site 4), and no lamprey were sampled downstream of the screens.

Figure 11. Aerial image (Google Maps, 2012) of Feed Canal, showing canal gates, fish screens, and approximate areas sampled (light blue) for early life-stages of Pacific lamprey (*Lampetra tridentata*) by electrofishing.

The one lamprey that was captured was initially seen just upstream of the screen structure, approximately where the electrode is in the water in Figure 12. Water temperature (°C) and conductivity (µs/cm) upstream of the screen at Feed Canal were 9.0 °C and 27.8 µs/cm. Downstream of the screen, temperature and conductivity generally tended to increase with distance downstream of the screen from 12.1 to 19.3 °C, and from 29.1 to 101.6 µs/cm. In general, sediment depths within the canal were greatest (~0.2 – 0.6 m) immediately above and below the screens in Feed Canal (Figure 12 and Figure 13). Sample locations 3 through 11 did not contain much sediment > 0.05 m deep. However, sites 7, 8, and 10 did contain soft sediment at depths up to ~ 0.1 m.

Figure 12. Confederated Tribe of the Umatilla Indian Reservation employees electrofishing Reclamation's Feed Canal (location 1, sample site 4) immediately upstream of the canal fish screening facilities to determine presence/absence of ammocoete Pacific lamprey (*Lampetra tridentata*). Sample locations immediately above and below the screens in Feed Canal contained the most soft sediment (type-I habitat) of depths > 0.2 m.

Figure 13. Confederated Tribe of the Umatilla Indian Reservation employees electrofishing Reclamation's Feed Canal (location 2, sample site 1) immediately downstream of the canal fish screening facilities to determine presence/absence of ammocoete/macropthalmia Pacific lamprey (*Lampetra tridentata*).

Maxwell Canal

Lamprey sampling in Maxwell Canal resulted in a total of 25 sample locations, 13 upstream of the canal fish screens and 12 downstream of the screens (Figure 5, Figure 14). Two sites were sampled within each location, resulting in total area upstream of 290 m^2 sampled over 328 minutes, and a total area downstream of 285 m^2 downstream of the screen sampled over 264 min. No lamprey were sampled at any locations in Maxwell Canal. Range of water temperature, conductivity and dissolved oxygen levels above and below the fish screens were 11.5 – 16.0 °C, 156.3 – 196.0 µs/cm, and 15.6 - > 20.0 mg/L, and 9.3 – 15.8 °C, 169.9 – 663.0 µs/cm, and 4.65 – 19.3 mg/L, respectively. Based on our limited data, changes in water temperature appeared to be a result of changes in atmospheric temperature. Of the Reclamation canals sampled, Maxwell (above and below the screening structures) contained the greatest proportion of type-I habitat, as all locations, except locations 8, 18, and 21 (Appendix A, Table 2a), consisted of primarily soft sediment > 0.1 m in depth. Also, Maxwell Canal contained the highest densities of aquatic vegetation, which could have contributed to the elevated dissolved oxygen levels observed (Figure 15).

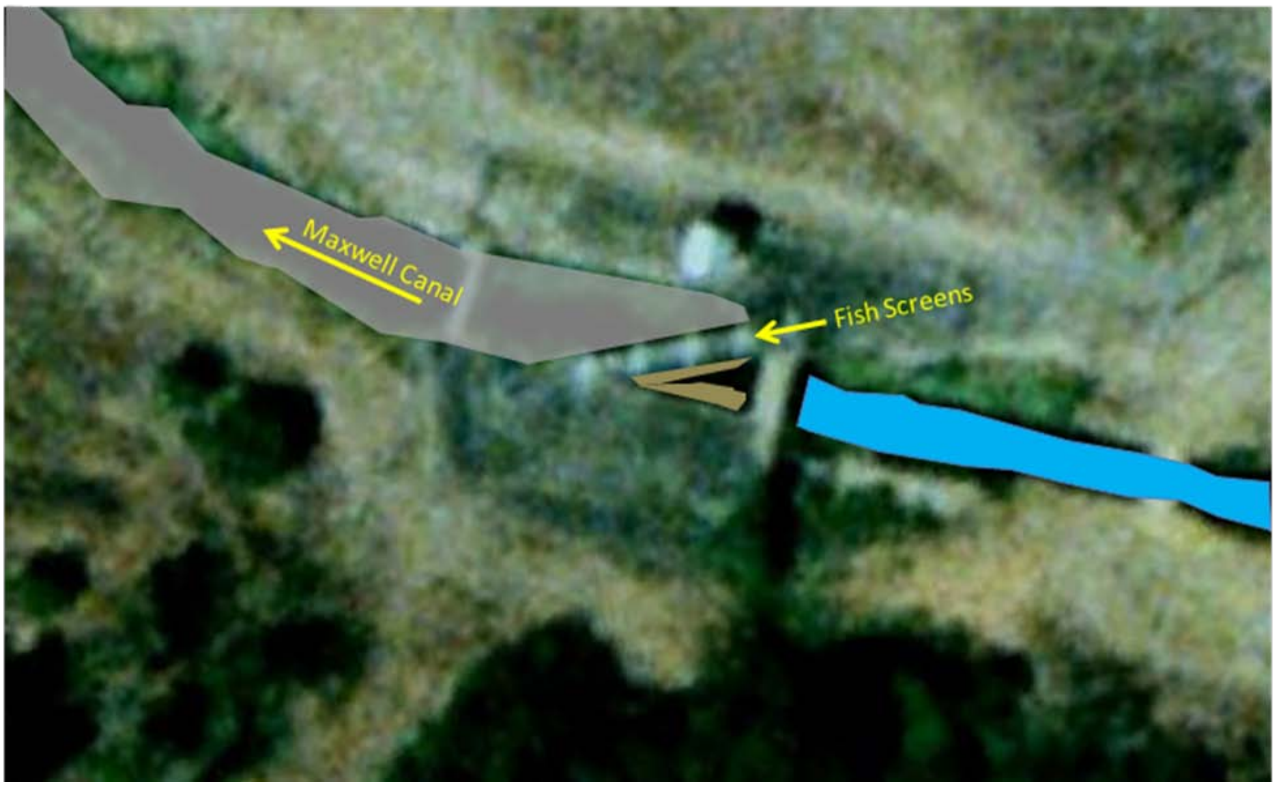

Figure 14. Aerial image (Google Maps, 2012) of Maxwell Canal, showing fish screens, de-watered areas (light grey), and approximate areas sampled for early life-stages of Pacific lamprey (*Lampetra tridentata*) by electrofishing (light blue) and by pitchfork or hand (brown).

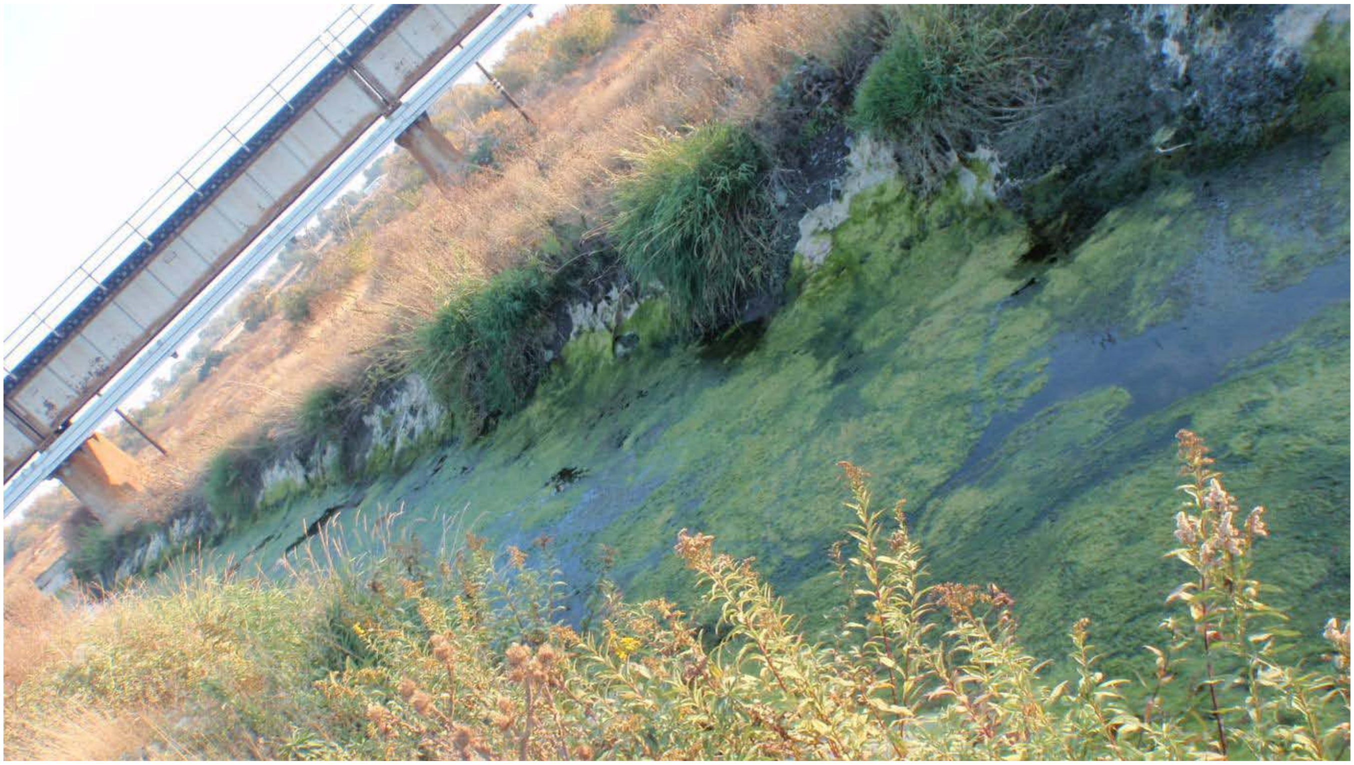

Figure 15. Of the three Reclamation Canals sampled, Maxwell Canal contained the greatest proportion of available type-I habitat (soft sediment) at depths > 0.1 m, but also contained significant amounts of aquatic vegetation.

West Extension Canal

A total of 5 locations, comprising 24 sites, were sampled for lamprey in West Extension Canal (see Figure 7). Only one location, consisting of four sites, was sampled above the fish screens (Figure 16). This entire sampled location was ~ 124 m^2 (31 min and 27 sec of sampling time) and consisted of the entire wetted area directly above the screen to the headworks. Similarly, the majority of the bay, downstream of the screens to the canal gates was sampled (total wetted area = ~ 76 m^2; Figure 16). This area consisted of five independent pools of water that required 35 min and 42 sec of total sampling time. Additionally, upon returning to this area the day following the described sampling techniques, the irrigation district personnel had raised the drum screens for maintenance, so the inside of each screen was visually inspected for lamprey, with one being found inside the furthest downstream drum screen.

From the post-screen bay to the end of the canal, 3 additional locations and 19 additional sites were sampled (Figure 7 and 17), resulting in 285 m^2 sampled over 209 min. Sites within each location in West Extension Canal ranged from one to eight (Appendix A, Table 3a). Range of water temperature, conductivity and dissolved oxygen levels above and below the fish screens were 5.9 – 8.9 °C, 251.4 – 450.7 µs/cm, and 6.55 – 11.35 mg/L, and 3.6 – 12.9 °C, 183.9 – 642.0 µs/cm, and 11.87 – 13.45 mg/L, respectively. Most of West Extension Canal, downstream of the post-screen bay, was concrete lined and contained very little soft sediment at significant depths (> 0.1 m). The considerable distance between sampling locations 4 and 5 is because that entire stretch of the canal is concrete-lined and would afford very little chance of lamprey collecting there upon dewatering (Chet Sater, pers. comm.). Of the canals sampled, the majority (13 of 14) of lamprey were collected, pre-screen, from West Extension Canal.

Mean length (± standard deviation) of ammocoetes and macropthlamia, collected above the screening facilities, were 149.5 mm (± 4.5 mm) and 157.1 mm (± 8.1 mm). The single macropthalmia collected in the drum screen (screen #4, most northern screen) was 156 mm in length. Interestingly, only two of the 13 lamprey recovered were sampled by electrofishing, while 10 were recovered as a result of visually inspecting the area. These individuals were presumably left stranded after canal dewatering, and had evacuated their burrows in an attempt to acquire more suitable habitat. Notably, previous sampling by CTUIR typically collected more lamprey than was observed in 2011 (Aaron Jackson pers. comm.) and 2011 was noted by irrigation district personnel on site as "considerably fewer lamprey than usual" seen or collected by fish salvage efforts in the forebay area as water drains out (Brett Brooks, pers comm).

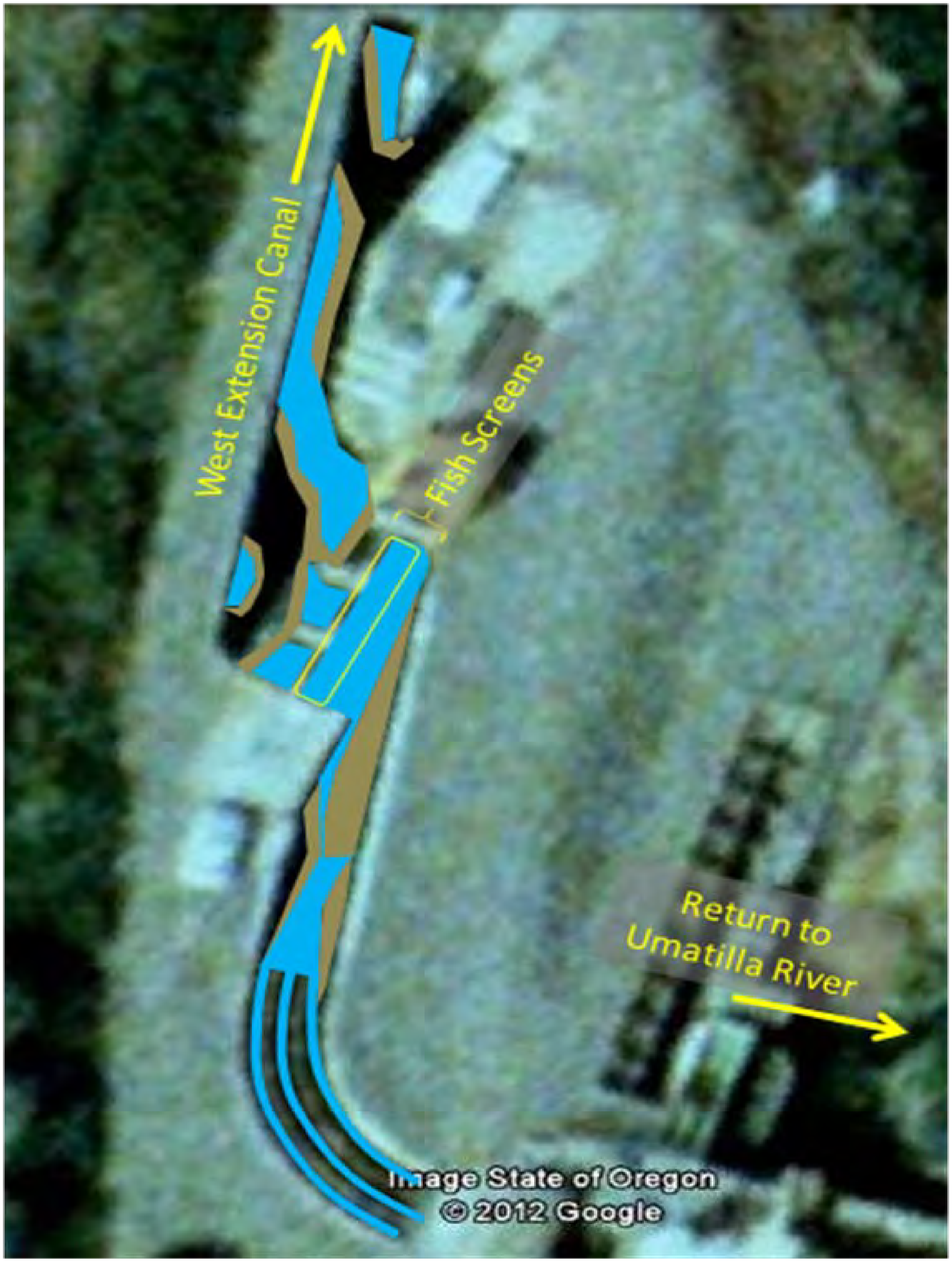

Figure 16. Aerial image (Google Maps, 2012) of West Extension Canal, showing fish screens, and approximate areas sampled for early life-stages of Pacific lamprey (*Lampetra tridentata*) by electrofishing (light blue) and by hand or pitchfork (brown).

Figure 17. – Reclamation biologists electrofishing for Pacific lamprey (*Lampetra tridentata*) in Reclamation's West Extension Canal (near Hermiston, OR) downstream of the fish screening facilities and just upstream of the canal's first stop structure.

Recommendations

Systematic sampling in 2011 of all three Reclamation canals on the Umatilla River yielded very few lamprey overall, and no lamprey were found beyond the screen structures at any of the facilities. Further work may be needed to better understand the interactions of lamprey (larvae and juveniles) with project structures. This first year of sampling seems to have unusually low numbers of lamprey ammocoetes and macropthalmia observed around these structures. This water year was characterized by an extremely cool spring resulting in later than normal runoff and unusually high flow events prior to sampling that may have altered "typical" behavior and migration patterns of lamprey. Similar sampling efforts, on an annual basis, would continue to provide information regarding presence/absence of Pacific lamprey in regional Reclamation canal systems under a variety of flow conditions and allow an estimate of the number of lamprey stranded in canals and screening facilities upon dewatering after irrigation season. However, other sampling methods and experiments could provide a more complete picture by allowing for the quantification of lamprey actively entrained into diversions and past screening structures. For example, a mark-recapture experiment, using individually marked (e.g., PIT tags) or batch marked (e.g., coded wire tags, visible implant elastomer tags) ammocoete lamprey released in the mainstem Umatilla River upstream of water diversions in the region, and completing active (i.e., electrofishing, fyke netting) or passive (i.e., fixed PIT tag antenna arrays and or PIT tag backpack units) sampling efforts in canals could be used to determine the proportion of lamprey released in the river subject to entrainment into the canal. This experiment could also help determine the efficiency of screens in the field setting by comparing the disposition of lamprey once they enter the canal system (i.e. bypassed back to river vs. going through screens and on down the canal). Furthermore, rates of juvenile lamprey entrainment could be enumerated by employing a fyke net system customized to sample unmarked drifting ammocoetes in the canal below the screens as well as bypass flows giving us a total number of lamprey that were: 1. Entrained into the canal 2. bypassed back into the river and 3. passed through the drum screens. These types of studies are more intensive than the post shut-down canal sampling and it may not be feasible to do them at every structure. These results and individual characteristics of the project features could be used to prioritize further study. Results of this study indicate West Extension Canal would be a logical structure for more intensive sampling simply because the most lamprey were found directly above this canal's screens. The construction of the canal and gate below the screens are conducive to a netting array that could net the entire flow in the canal. However, it may also be beneficial to take advantage of existing infrastructure, and differences in design that may make one location more desirable over another for additional sampling. For example, it may be possible to use existing PIT tag array systems at locations on the Umatilla River (at Feed Diversion Dam), Feed Canal just downstream of the headworks and upstream of the screening facility, and develop similar arrays downstream of the screening facility and Feed Canal bypass to quantify canal entrainment and screen loss. Additionally, the existing structures of this particular diversion are not as feasible for large-scale fyke net deployment as those found at the Maxwell or West Extension canals.

Considerations for Sampling Design

Utilization of existing PIT tag antenna arrays placed in the canals above screens would be advantageous in that we would only need to add antenna arrays downstream of screens to estimate entrainment loss. These arrays are sturdy and reliable but would be limited to the utilization of ammocoetes greater than 120 mm. If it is determined that ammocoetes less than 120 mm are more prone to entrainment due their small size allowing them to pass through drum screens designed for salmon smolts, their size may be a limiting factor for PIT tag techniques. Mueller et al. (2006) reported that ammocoetes down to 120 mm could effectively be tagged without extremely adverse effects when using 12 mm PIT tags. If it is determined that the smaller lifestages of ammocoete are to be targeted then batch mark and recapture (e.g., coded wire tag, visible implant elastomer tag) techniques that require sampling the entire canal flow below the screens may be in order. To design a netting array that would give us the ability to sample the entire flow may prove logistically difficult given the size and dimensions of the canals. However, an advantage to this technique is that the entire flow is sampled giving very accurate estimate of lamprey entrainment. Possible locations for netting arrays at West Extension, Feed and Maxwell canals are available for consideration in Appendix B.

An alternative to mark-recapture techniques or complete sampling of diverted water would be to sub-sample the flow above and below the screens with ichthyoplankton nets and determine the number of ammocoetes captured per volume of water sampled in the net then extrapolate larval captures as an estimate for the entire canal flow. Advantages to sub sampling include logistical ease with which equipment can be deployed, basically any location along the canal can be sampled via a bridge or line and pulley system utilized to deploy nets and bring back to shore to be worked up. Whereas, disadvantages include compromised data accuracy, as the final product is an estimate based on extrapolation.

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Appendix A

Sample locations, gps coordinates, and total time and area sampled for Pacific lamprey sample sites in Feed, Maxwell, and West Extension Canals (near Hermiston, OR).

Table 1a. Sample locations on Feed Canal, gps coordinates, total number of sample sites and sample time, and total number of Pacific lamprey sampled within each sample location. Dotted vertical line (between locations one and two) isolates sample locations above and below the canal fish screening facilities. [A] GPS coordinates reported are those taken at the lowest downstream location within each sample location. [B] Sample sites 7 and 8 in sample location 1 (upstream of screening facilities) were larger than the 7.5 m^2 plots used for all other sites, and took 95 and 61 minutes (156 total) to complete our sampling effort.

Sample Location (ID)	[A]Location Coordinates		Sample Sites (#)	Time Sampled (min)	Lamprey Sampled	Location/Comments
	Lat	Long				
1	45.721	-119.177	8[B]	66/156[B]	1	Upstream of screens, soft silt sediment, see Figure 2
2	45.806	-118.528	5	55	0	Immediately downstream of screens, see Figures 9 and 10
3	45.725	-119.181	4	44	0	0.37 km downstream of screens, see Figure 1
4	45.730	-119.183	2	22	0	0.58 km downstream of screens
5	45.740	-119.190	2	22	0	100 m upstream of E. Gerone St Bridge in Echo, OR
6	NA	NA	1	11	0	Immediately upstream of S. Howards Rd Bridge
7	45.840	-119.237	4	44	0	Downstream of screens
8	45.790	-119.205	4	44	0	Two sites upstream and downstream of S.Edwards Rd Bridge
9	45.804	-119.174	0	0	0	No electrofishing conducted at site, minimal type-I habitat
10	45.779	-119.190	4	44	0	Upstream of Bartley Rd Bridge
11	45.759	-119.209	4	44	0	Upstream of Insterstate Highway 84
12	45.749	-119.203	4	44	0	Downstream of Highway 395

Table 2a. Sample locations on Reclamation's Maxwell Canal, gps coordinates, total number of sample sites and sample time, and total number of Pacific lamprey sampled within each sample location. Dotted vertical line (between locations 12 and 13) isolates sample locations above and below the canal fish screening facilities. [A] GPS coordinates reported are those taken at the lowest downstream location within each sample location.

Sample Location (ID)	[A]Location Coordinates		Sample Sites (#)	Time Sampled (min)	Lamprey Sampled	Sample Site ID/Comments
	Lat	Long				
2	45.802	-119.356	3	33	0	Sites MC1-MC3, upstream of screens
1	45.802	-119.354	2	110	0	Sites MCTA-B
3	45.802	-119.352	2	22	0	Sites MC4-MC5
4	45.802	-119.349	2	22	0	Sites MC6-MC7
5	45.802	-119.346	2	22	0	Sites MC8-MC9
6	45.801	-119.344	2	22	0	Sites MC10-MC11, intermittent sampling
7	45.800	-119.342	2	22	0	Sites MC12-MC13, deeper water (~12")
8	45.798	-119.341	2	22	0	Sites MC14-MC15, primarily small cobble substrate
9	45.797	-119.338	2	22	0	Sites MC 16-MC17, primarily soft silt sediment
10	45.797	-119.335	2	22	0	Sites MC18-MC19, primarily soft silt sediment
11	45.796	-119.332	2	22	0	Sites MC20-MC21, primarily soft silt sediment
12	45.796	-119.33	2	22	0	Sites MC22-MC23, primarily soft silt sediment
13	45.805	-119.36	2	22	0	Sites MC24-MC25, dense aquatic vegetation, soft sediment
14	45.807	-119.361	2	22	0	Sites MC26-MC27, dense aquatic vegetation, dense soft sediment
15	45.808	-119.358	2	22	0	Sites MC28-MC29
16	45.808	-119.356	2	22	0	Sites MC30-MC31, soft silt sediment
17	45.807	-119.354	2	22	0	Sites MC32-33, upstream of wasteway, sand/silt, leaf litter
18	45.811	-119.342	2	22	0	Sites MC34-MC35, small gravel/silt, *started 15 m^2 plots*

19	45.815	-119.333	2	22	0	Sites MC36-MC37, dense silt, upstream of Minnehah Rd
20	45.820	-119.321	2	22	0	Sites MC38-MC39, dense silt, 12" water depth, Upstream of Lloyd Ln
21	45.822	-119.311	2	22	0	Sites MC40-MC41, gravel, intermittent pools (8" deep), Hwy 107 crossing
22	45.839	-119.259	2	22	0	Sites MC42-MC43, soft sediment, 12" water depth, Townsend Rd crossing
23	45.843	-119.249	4	44	0	Sites MC44-47, soft sediment, deep pools, end of canal (Ott Rd)

Table 3a. Sample locations on Reclamation's West Extension Canal, gps coordinates, total number of sample sites and sample time, and total number of Pacific lamprey sampled within each sample location. Dotted vertical line (between locations 1 and 2) isolates sample locations above and below the canal fish screening facilities. [A] GPS coordinates reported are those taken at the lowest downstream location within each sample location. [B] Two macropthalmia sampled with electrofishing gear, nine macropthalmia and two ammocoetes were stranded in dewatered areas and captured by hand. [C] Though no lamprey were recorded as being sampled below the screening facilities, one lamprey was sampled inside a drum screen after canal dewatering.

Sample Location (ID)	[A]Location Coordinates		Sample Sites (#)	Time Sampled (min:sec)	Lamprey Sampled	Location/Comments
	Lat	Long				
1	45.882	-119.326	1	31:27	[B]13	Inundated areas directly upstream of drum screens, see Figure 5
2	45.883	-119.326	1	35:42	[C]0	Inundated areas directly downstream of drum screens, see Figure 5
3	45.903	-119.331	8	88	0	2.4 km downstream of West Extension Canal headworks, see Figure 13
4	45.911	-119.357	7	77	0	~2.4km/1.5mi downstream of Location # 3
5	45.833	-119.769	6	66	0	Near canal's termination

Appendix B

Aerial images (Google Maps, 2012) showing possible net locations for monitoring entrainment of larval and juveniles Pacific Lamprey (*Lampetra tridentata*).

Figure 1b. Aerial image (Google Maps, 2012) of Feed Canal, showing fish (drum) screens, and possible netting locations for evaluating entrainment of early life-stages of Pacific lamprey (*Lampetra tridentata*).

Figure 2b. Aerial image (Google Maps, 2012) of Maxwell Canal, showing fish (drum) screens, and possible netting locations for evaluating entrainment of early life-stages of Pacific lamprey (*Lampetra tridentata*).

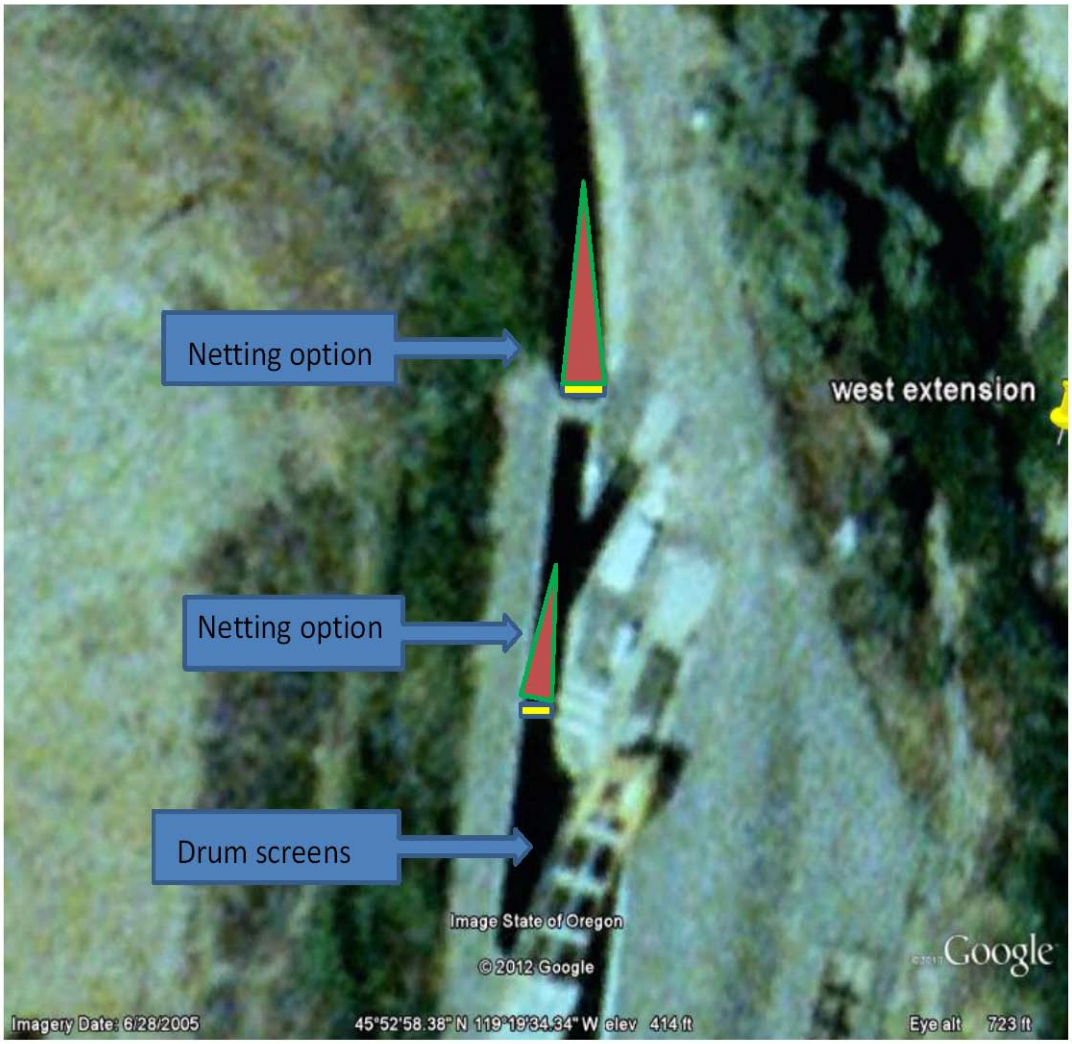

Figure 3b. Aerial image (Google Maps, 2012) of West Extension Canal, showing fish (drum) screens, and possible netting locations for evaluating entrainment of early life-stages of Pacific lamprey (*Lampetra tridentate*

APPENDIX C

Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversions - 2011 Annual Report

Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversions
2011 Annual Report

Andy Johnsen, Mark C. Nelson and R.D. Nelle

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
Leavenworth, WA

Project Numbers:
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U.S. Army Corps of Engineers
U.S. Bureau of Reclamation

October 14, 2011

On the cover: Pacific lamprey code 51 passing the counting window in the left fishway at Prosser Dam, July 26, 2011. Photograph from the counting video, courtesy of Jeff Trammell, Yakama Nation Fisheries Program.

Disclaimers

The correct citation for this report is:
Johnsen, A., M.C. Nelson, and R.D. Nelle. 2011. Passage of radio-tagged adult Pacific lamprey at Yakima River diversions. 2011 Annual Report. U.S. Fish and Wildlife Service, Leavenworth, WA. 27 p.

PASSAGE OF RADIO-TAGGED ADULT PACIFIC LAMPREY AT YAKIMA RIVER DIVERSIONS 2011 ANNUAL REPORT

Andy Johnsen, Mark C. Nelson, and R.D. Nelle

Final Report

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
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Abstract- The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River and its tributaries. Numbers of adult lampreys returning to the tributaries have declined in recent years due to several contributing factors including hydroelectric and diversion dam operations, habitat degradation, and pollution. The Yakima River has several diversion dams that may be obstacles in the upstream migration of adult Pacific lamprey. Lampreys are known to pass some of these dams but very little is known about their residence times and passage routes. We used radio telemetry to determine approach timing, residence time, fishway routes, other passage routes, and migration rates at the diversion dams on the Yakima River. Wanawish, Prosser, and Sunnyside dams were equipped with telemetry stations. Stations were also established on Satus and Toppenish creeks and near the mouth of the Yakima River. Eight Pacific lampreys, collected at John Day Dam the previous summer, were radio-tagged and released above and below Wanawish Dam on March 30, 2011. Five lampreys made upstream movements and approached at least one dam. Three lampreys were depredated or scavenged by mammalian predators. Upstream movements were made during periods of decreasing discharge and mostly during night hours. Lampreys made first approaches at the dams between April 1 and August 2. One lamprey successfully passed through Wanawish Dam. Two were successful in passing Prosser Dam. One lamprey moved up to Sunnyside Dam but did not pass before the transmitter battery died. For lampreys that passed a dam, total residence time ranged from 29.9 to 81.1 days with fishway passage times between 0.15 and 6.33 days. The average migration rate between dams was 11.35 km/day. Our sample size was small but initial results indicate that while the diversion dams on the Yakima River are passable by adult Pacific lamprey, they appear to be impediments to upstream migration. As the study continues, we will adaptively modify the telemetry stations and tag and release greater numbers of lampreys to gather more detailed information on movements at the dams.

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Introduction

The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River Basin. It is found in many of the same tributaries as other anadromous fishes such as steelhead *Oncorhynchus mykiss* and Chinook salmon *O. tshawytscha*. In comparison to these salmonids, however, relatively little is known about the life history of Pacific lamprey.

Most adult Pacific lampreys return to freshwater from February to June (Kostow 2002). It is thought most do not home to their natal streams, unlike many anadromous fishes, but instead may utilize the "suitable river strategy" in which returning adults are attracted to streams inhabited by larval lamprey or ammocoetes (Waldman *et al.* 2008). Recent genetic studies indicate Pacific lampreys are panmictic (Goodman *et al*. 2008 and Docker 2010) and support the premise of no natal homing in Pacific lamprey.

Much of the information on adult Pacific lamprey migrations in freshwater was gathered by radio telemetry or inferred from counts at dams. Within the Columbia River, most telemetry studies of Pacific lamprey movements have focused on passage at mainstem dams (e.g. Moser *et al*. 2002, Johnson *et al*. 2009, Keefer 2009). These studies documented that hydroelectric dams cause major delays and difficulties for the upstream migration of Pacific lamprey, resulting in less than half of tagged fish successfully passing upstream through the fishways. Radio telemetry studies conducted in tributaries such as the John Day River (Bayer *et al*. 2000), the Willamette River (Clemens *et al.* 2011), and the Methow River (Nelson *et al*. 2009) found that Pacific lamprey entered these spawning tributaries in late summer, moved upstream, and then ceased migration to overwinter downstream of spawning areas before resuming migration in the spring prior to spawning.

Counts in the fishways at dams on the Columbia River have shown a sharp decline in the number of individuals returning to freshwater to spawn since the 1960's (Kostow 2002, DART 2011). Several factors including construction and operation of hydroelectric and diversion dams, river impoundment, water withdrawals, stream alteration, habitat degradation, elevated water temperatures, pollution, and ocean conditions have likely contributed to this decline (Luzier *et al.* 2011).

Pacific lampreys have ecological and cultural importance. Pacific lampreys can be a main dietary source for sea lions and seals as well as avian predators (Roffe and Matte 1984) and thus may act as buffers to predation on salmonids. Spawned out adults are sources of marine derived nutrients in tributaries and ammocoetes may play a major role in nutrient cycling. Native Americans in the Columbia Basin historically fished for Pacific lampreys at falls or rapids that impeded adult upstream migration. Interviews with tribal elders indicate that this once abundant species was utilized traditionally for ceremonial, sustenance, and medicinal purposes but has declined to the point where it is now rarely harvested (Close *et al*. 2001).

Pacific lampreys inhabit the Yakima River Basin (Patten *et al.* 1970) but very few have been counted at Prosser Dam in recent years (DART 2011). Details on upstream migration, timing, spawning, and distribution of Pacific lamprey in the Yakima River are not well understood. Several diversion dams in the Yakima River Basin may be impediments for adults migrating to suitable spawning areas. Adult Pacific lamprey have been observed in the fish ladders at Prosser Dam during the spring and fall months, but specific telemetry studies have not been conducted and little is known about their migration rates or residence time at the dams.

The objective of this radio telemetry study is to determine adult Pacific lamprey passage at the Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, time in the fishways, total time spent at the dams, and migration rates between dams. In addition, areas where Pacific lamprey over-winter and spawn in the Yakima River will be located if possible.

This annual report presents the initial results of our study through September 10, 2011.

Methods

Study Area

The Yakima River flows for 344 km, from the headwaters at Keechelus Lake in the Cascade Mountains to the confluence with the Columbia River at river kilometer (rkm) 539, and drains an area of approximately 15,941 km^2 (Figure 1). Annual mean discharge at the Kiona Gage Station (rkm 48.1) is 3,479 ft^3/s (range 1,293 – 7,055 ft^3/s), with the highest daily mean discharge of 59,400 ft^3/s recorded on December 24, 1933 and the lowest daily mean discharge of 225 ft^3/s recorded on April 4, 1977 (USGS 2011). The main tributaries include Satus Creek, Toppenish Creek, Naches River, Taneum Creek, Teanaway River, and Cle Elum River.

A complex irrigation network, managed in large part by the U.S. Bureau of Reclamation, makes the Yakima River basin one of the most intensely irrigated areas in the United States, and has served to make it a leading producer of tree and vine fruit as well as other diverse agricultural products. Six lakes and reservoirs, with a total active storage capacity of 1.07 million acre-feet, hold the spring and summer snowmelt in the mountains for delivery to irrigation districts between April and October (Fuhrer *et al.* 2004). Irrigation water is distributed throughout the network via rivers, creeks, and man-made canals. Irrigation diversion dams include Wanawish, Prosser, Sunnyside, Wapato, Roza, and Easton on the Yakima River and Cowiche and Wapatox on the Naches River (Figure 1).

Surface water diversions are equivalent to about 60 percent of the mean annual stream flow from the basin (Fuhrer *et al.* 2004). In spring, the stream flow reflects the quantity of water stored in the mountain snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs. During summer, return flows from irrigated land account for 50 to 70% of the flow in the lower Yakima River (Fuhrer *et al.* 2004).

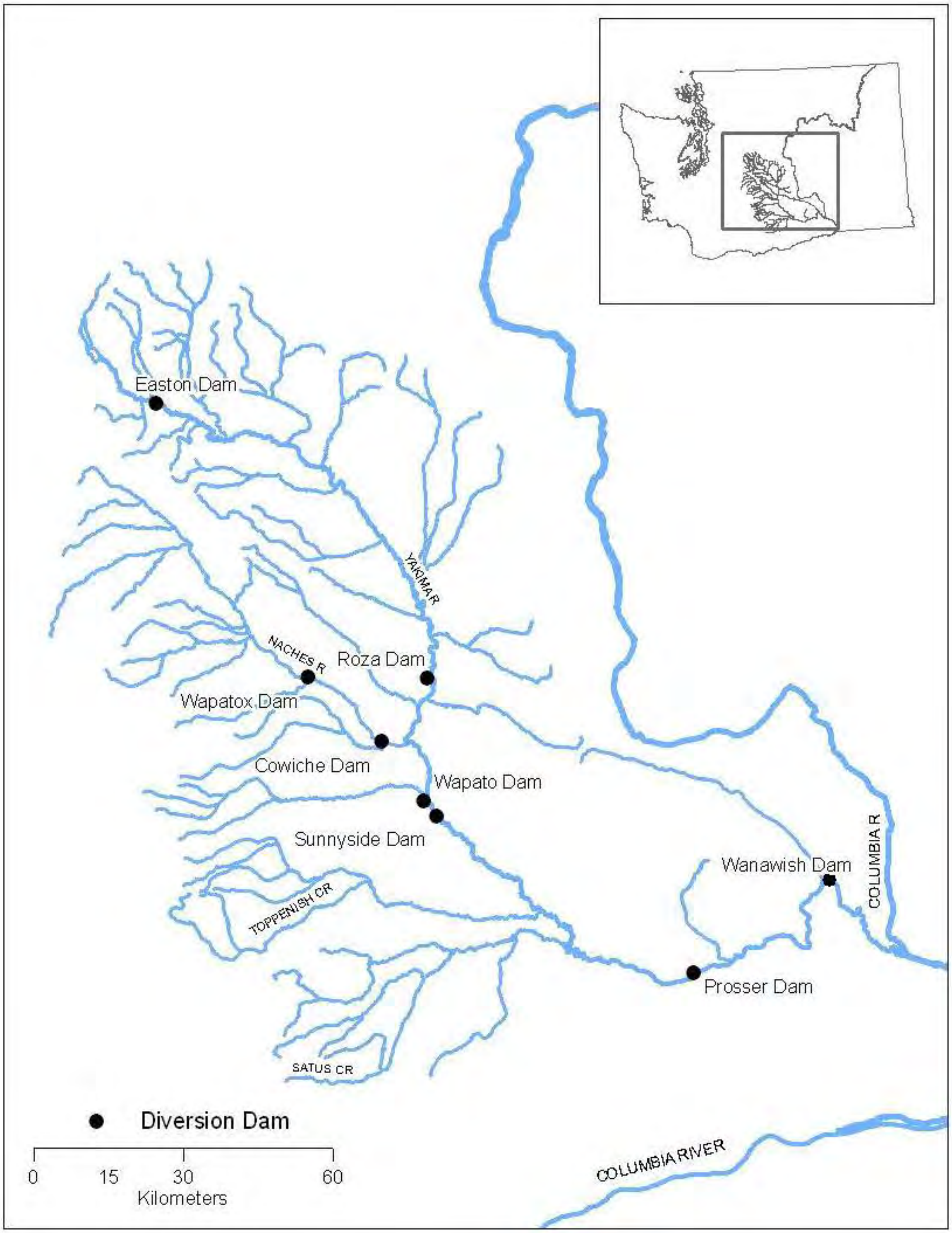

Figure 1. Map of the Yakima River watershed, showing the locations of the major diversion dams.

Fixed Stations

Fixed telemetry stations were set up at three diversion dams, in two tributaries, and near the mouth of the Yakima River (Figure 2). The basic layout at a diversion dam consisted of aerial antennas that monitored downstream of the dam, the face of the dam, and upstream of the dam. Underwater antennas monitored pools at the entrance, middle, and exit of each fishway. Aerial antennas were four-element Yagi-type and underwater antennas were constructed of coaxial cable with 100 mm of the inner wire bared at the end. Aerial antennas were mounted on masts and the underwater antennas were suspended on chains. Data recording telemetry receivers (Lotek SRX-400A), equipped with an antenna switching unit (Grant Engineering Hydra) programmed on a "master-slave" cycle, were housed in a metal box at each station. AC power was used to charge the external 12v battery that powered the receiver at each diversion station. Solar panels were used as a back-up power system in case AC power was lost.

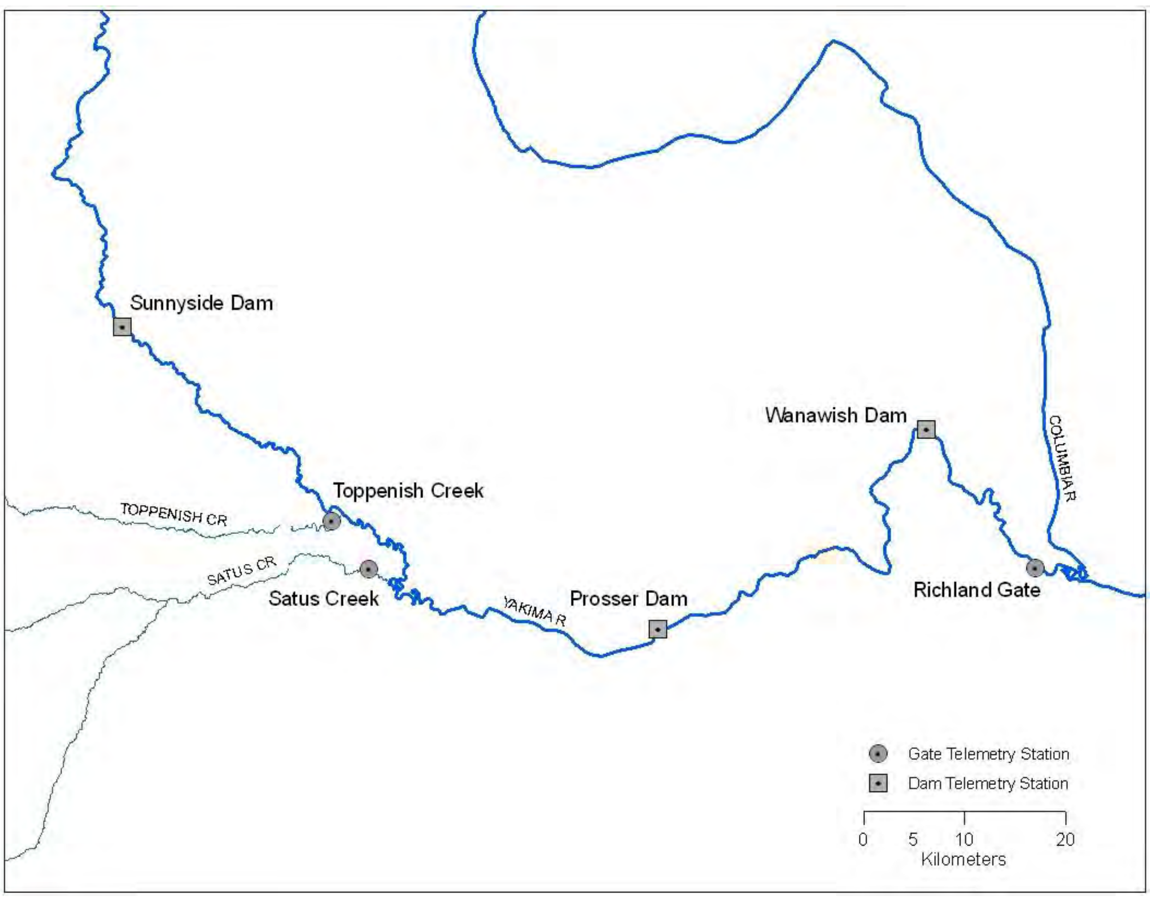

Figure 2. Map of the lower Yakima River basin showing the locations of fixed telemetry stations in 2011.

Wanawish Dam
Wanawish Dam, constructed in 1892 at rkm 29, is a rock filled timber crib dam with a concrete face. It is 160 m long and approximately 2 m high and diverts water into canals on both banks of the river. Fishways, consisting of an entrance pool and 4 vertical slot pools, are located on each bank at the dam, with the fishway exit near the mouth of each canal (Figure 3). Both fishways at the dam had one aerial antenna facing downstream, one upstream, and one across the face of the dam. An underwater antenna was located at the entrance, middle, and exit pool of each fish ladder as well as the entrance to the irrigation canal on river left (Figure 3).

Prosser Dam
Prosser Diversion Dam, constructed in 1904 by private interests and now operated by the U.S. Bureau of Reclamation, is located at rkm 75. The facility consists of a concrete weir structure, an irrigation canal (1,500 ft^3/s capacity) on the left bank, three vertical slot type fishways (one on the right bank and two mid-river "islands" on the dam), an adult sampling facility (in the right bank fishway), and a juvenile bypass and sampling facility (downstream at the canal screen structure). The structural height of the dam is 2.7 m and the weir crest length is 201 m (USBOR 2011). The right bank fishway had one aerial antenna monitoring downstream and one upstream; underwater antennas were located at the high water entrance, the low water entrance, the middle, and exit pools of the fish ladder (Figure 4). The center island fishway had one downstream aerial antenna and two upstream aerial antennas (combined as one unit); underwater antennas were at both entrance pools and the exit pool of the fish ladder (Figure 4). The left island fishway was equipped with aerial antennas monitoring upstream, downstream, and across the face of the dam both to the left and right of the island; underwater antennas were located within the entrance, middle, and exit pool of the fish ladder (Figure 4).

Sunnyside Dam
Sunnyside Diversion Dam, located at rkm 167, was completed in 1907. It is a concrete ogee weir with embankment wing and a canal (1,320 ft^3/s capacity) on the left bank. The structural height is 2.4 m and the weir crest length is 152 m (USBOR 2011). Fish passage facilities consist of three stair step ladders, one on each bank and one near the center of the dam. The left bank fishway had one upstream aerial antenna and two downstream aerial antennas (combined as one unit); underwater antennas were located in the entrance, center, and exit pool of the fish ladder (Figure 5). The center island fishway was equipped with a total of five aerial antennas: two (combined as one unit) monitored downstream, one monitored the right face of the dam, and two monitored upstream on either side; underwater antennas were located in both entrance pools and a middle pool of the fish ladder (Figure 5). A fixed station was not installed on the right bank fishway due to access issues. The right bank fishway was open, however, it was not maintained or cleaned and it is unknown whether it was passable by lamprey.

Gate Stations
A station near the mouth of the Yakima River (rkm 6.9) was set up to use as "gate" to determine if Pacific lamprey moved out of the study area. This fixed station consisted of one aerial antenna aimed across the river, a SRX400A receiver, and a car battery charged

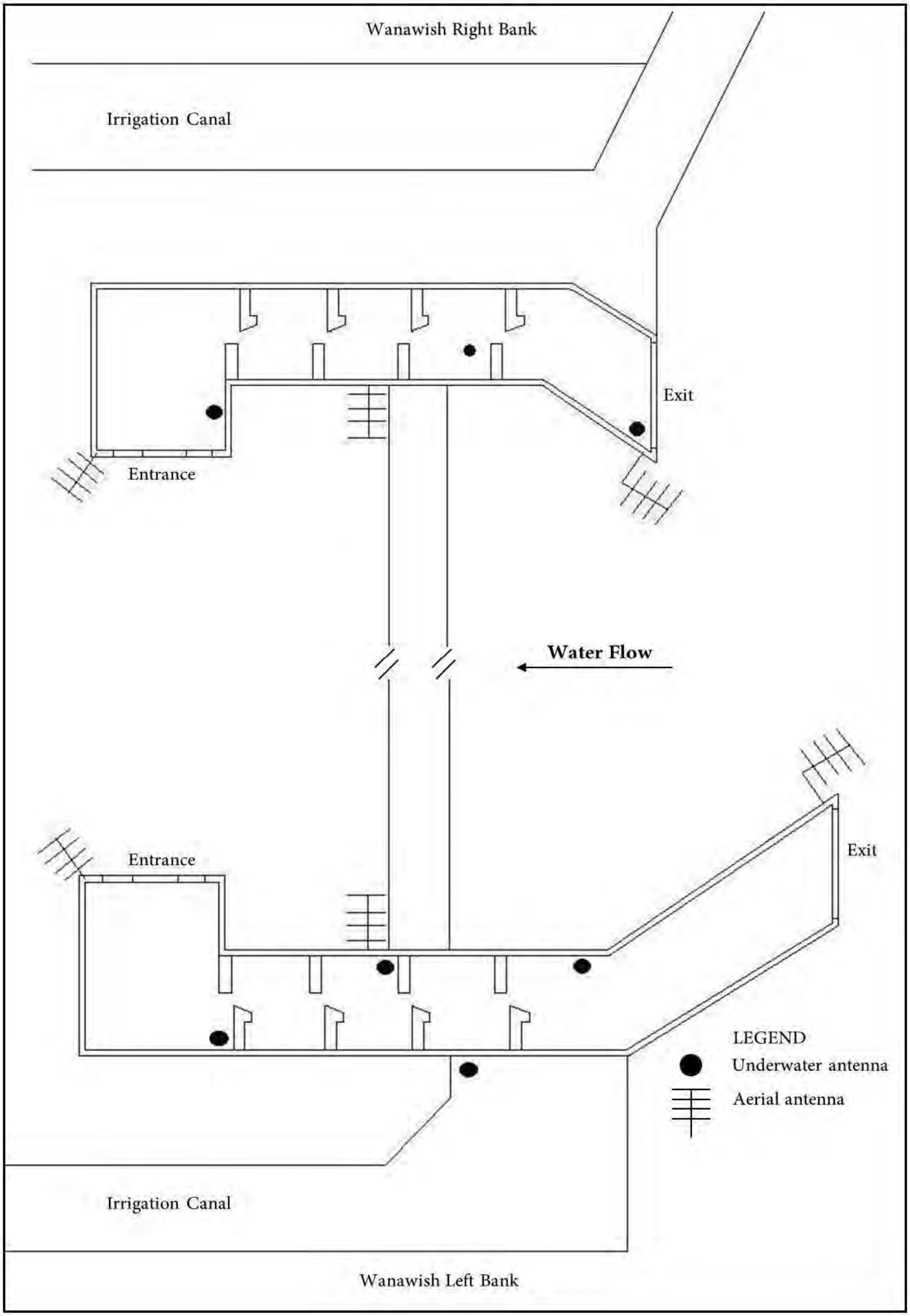

Figure 3. Locations of telemetry antennas on right and left bank fishways at Wanawish Dam, 2011.

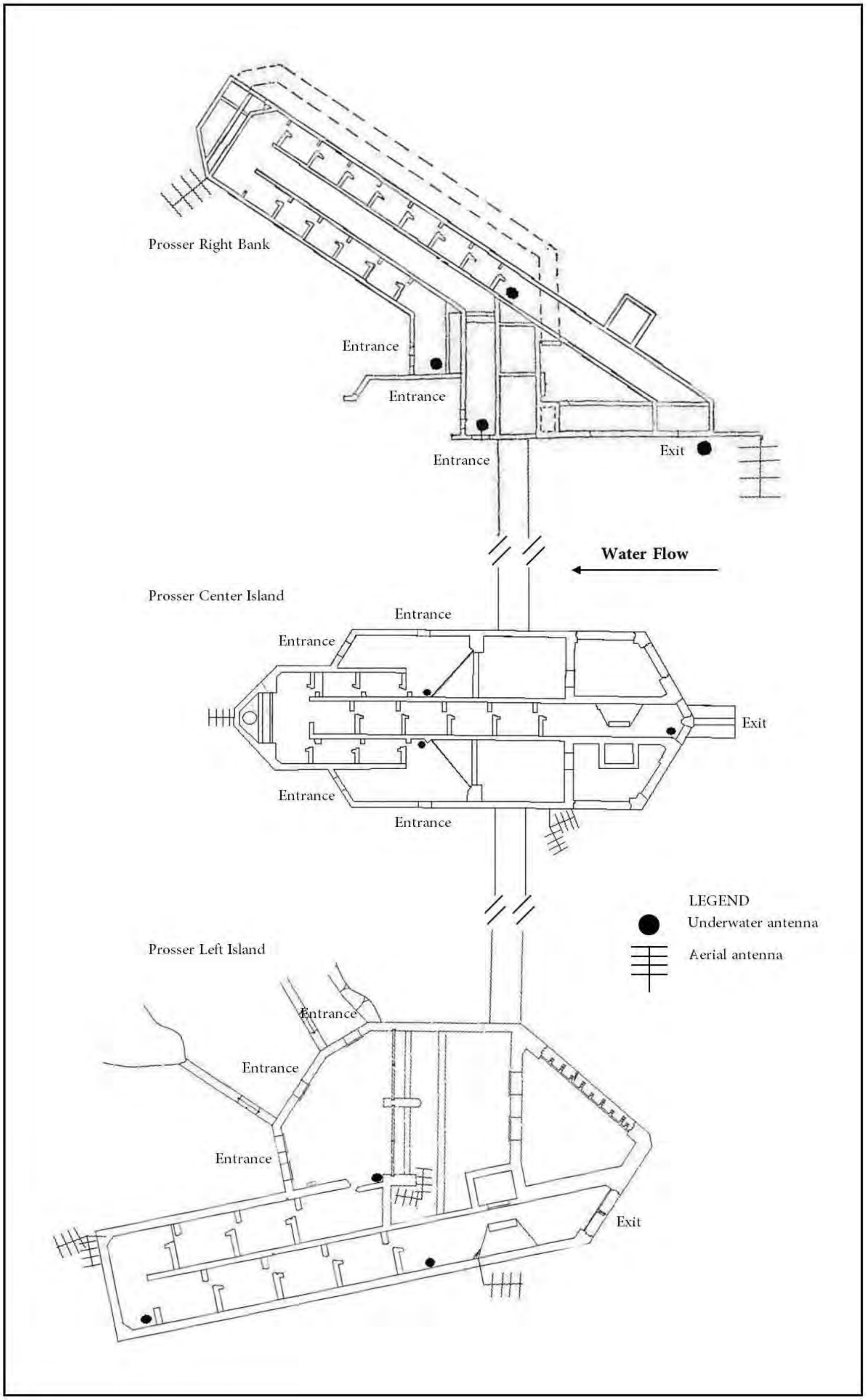

Figure 4. Locations of telemetry antennas on right, center, and left fishways at Prosser Dam, 2011.

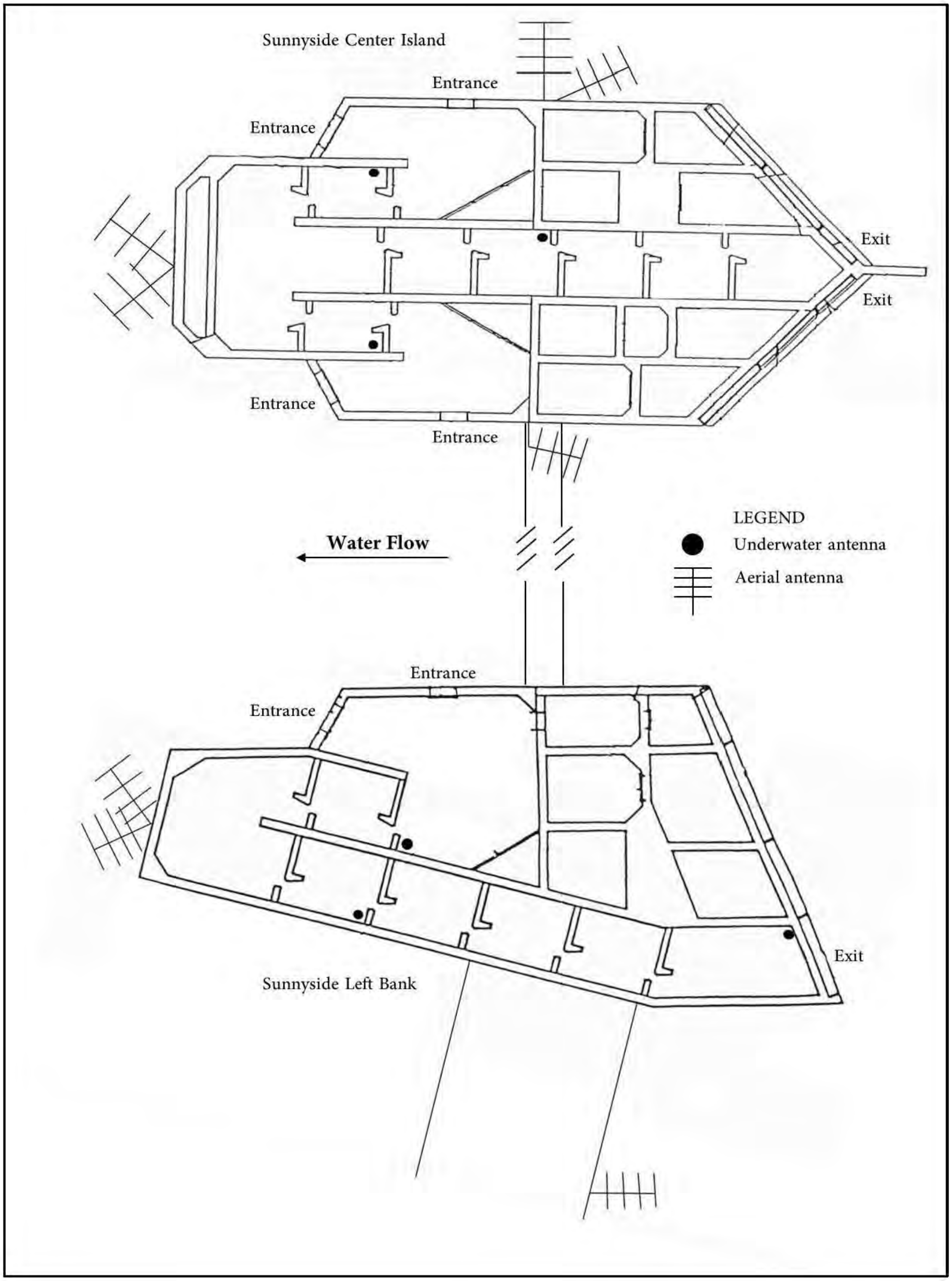

Figure 5. Locations of telemetry antennas on center and left bank fishways at Sunnyside Dam, 2011.

by AC power provided by the landowner. Gate stations were also set up on Satus and Toppenish creeks to determine movement into these tributaries (Figure 2). These stations each had one antenna facing upstream and one facing downstream combined together as one unit. The receivers at these stations were powered by solar panels.

Telemetry Data Analysis

For descriptive purposes, the definitions of *left* and *right* are referenced to the downstream or river flow direction, and apply to the river banks as well as the island fishways at the dams. *First approach* is defined as the first detection recorded on an aerial antenna at a fixed telemetry station. *Below dam residence* is calculated as the difference between the first downstream detection at the dam and the first detection of entry into the fishway during a passage event. *Fishway passage* is calculated as the elapsed time between the first fishway entrance detection and the last fishway exit detection during a passage event. *Above dam residence* at a dam is defined as the difference between the last fishway exit detection and the last upstream aerial antenna detection. *Migration time* is calculated as the difference between the last detection as the lamprey moved from one station to the first detection at the next station. *Migration rate* is defined as migration time divided by the distance between stations.

Collection

Adult Pacific lampreys were supplied by the Yakama Nation Fisheries Program from collections at John Day Dam on the Columbia River (rkm 347) between August 15 and September 21, 2010. Fish were captured in funnel traps at the picketed leads of the fish counting stations on both sides of the dam and held at the Yakama Nation Klickitat Salmon Hatchery facility. On January 30, 2011, they were transferred to the Yakama Nation Prosser Hatchery facility and held until tagged. Prior to being transported between facilities the lampreys were screened for fish health issues by the USFWS Lower Columbia Fish Health Center. One lamprey tested positive for furunculosis. Subsequently all were injected with an antibiotic (0.1 – 0.15 cc of Oxytetracycline) to prevent the spread of disease (Patrick Luke, Yakama Nation Fisheries Program, pers. comm.). At both facilities the fish were held in flow-through metal stock tanks supplied with river water.

Radio Transmitter Implantation

Implantation surgeries took place in the spawning shed at the Yakama Nation Prosser Hatchery facility. The surgical procedure was modified from methods described in Moser *et al.* (2002) and Nelson *et al.* (2007). Tools and transmitters were chemically disinfected with Benz-All®. Fish were anesthetized in a bath of 80 ppm tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate to match the pH of the river water. After 8 to 10 minutes the fish was removed from the bath and total length (mm), interdorsal base length (mm), girth (mm), and weight (g) were measured and recorded. Sex was determined by examining the differences in shape of the dorsal fins (Patrick Luke, Yakama Nation Fisheries, pers. comm.) and later verified by the presence of eggs or testes. The lamprey was then placed on a cradle made from PVC pipe and the head and gills were immersed in a 15 L bath of 40 ppm of buffered MS-222. Wet sponges were placed in the cradle to prevent the lamprey from sliding and to assist in incision placement. Using a number 12 curved blade scalpel, a 20 mm incision was made 1 cm off the ventral midline with the posterior end of the incision stopping in line with the anterior end of the first dorsal fin. A catheter was inserted through the incision and out the body wall approximately 4 cm posterior to the incision. The antenna was threaded through the catheter and the individually coded radio transmitter (Lotek NTC-4-2L, 8 x 18 mm, 2.1 g, 162 d battery life) was inserted into the incision. Using a 19 mm needle the incision was then closed with 3-4 braided absorbable sutures. The lamprey was then transferred to an oxygenated 600 L recovery tank used for transportation to the release sites. All lampreys were held for a minimum of 1.5 hours before release.

Release

Release sites were located both upstream and downstream of Wanawish Dam. To reduce bias in the approach of fish to the dam, tagged lamprey were released on both sides of the river downstream of the dam. Release sites were chosen by accessibility and relative close proximity to Wanawish Dam. Individuals were chosen for each release site by removing them from the recovery tank at random. The code of each fish was then recorded prior to release.

Tracking

Fixed telemetry stations were downloaded on a weekly schedule. Test beacons were activated during downloads at each station to ensure the antennas and receivers were operating and recording properly. In addition to the data recorded at fixed stations, mobile tracking was opportunistically conducted to determine exact locations at the dams as well as approximate locations between the dams. Mobile tracking was conducted by foot, truck, and boat.

Temperature

Stream temperatures were monitored at Wanawish, Prosser, and Sunnyside dams. Electronic data loggers (HOBO® U22 Water Temp Pro v2, Onset Computer Corp.) were calibration checked for accuracy with an NIST-tested thermometer and only units that agreed to within 0.2 °C were deployed. The data loggers were housed in perforated PVC pipe (40 mm dia.) and tethered to wire cable suspended into the river from one fishway at each dam. Data loggers were programmed to record once every hour. Data were downloaded into a shuttle, offloaded, and saved to a desktop computer. Mean, minimum, and maximum daily water temperatures were calculated with the Hoboware® Pro software package.

Discharge

Stream discharge was obtained from the USBOR Pacific Northwest Region Hydromet website (http://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html). Average daily flow (QD) was queried for the Yakima River stations at Kiona (KIOW) and Prosser (YRPW). Discharge is reported in cubic feet per second (ft^3/s).

Results

Tagging
A total of 8 adult Pacific lampreys were radio tagged on March 30, 2011 (Table 1). Five were female and 3 were male. Weights ranged from 217 to 418 g (mean 347 g), lengths from 520 to 670 mm (mean 601 mm) and girths from 90 to 115 mm (mean 103.5 mm).

Release
On March 30, 2011, all of the tagged lampreys were released in the vicinity of Wanawish Dam. Two lampreys (codes 47 and 54) were released from the left bank 1.2 km upstream of the dam, three (codes 49, 52, and 53) were released from the left bank 2.7 km downstream from the dam and three (codes 48, 50, and 51) were released from the opposite bank (Figure 6). Release locations were along the bank in areas with slower water and cover consisting of submerged grasses or an undercut bank. All lampreys sought cover immediately upon release. Mobile tracking on the following day indicated four lampreys had moved upstream and one downstream.

Table 1. Weight, total length, girth, dorsal base length, sex, and release location of adult Pacific lamprey radio-tagged and released in the Yakima River on March 30, 2011.

Code	Weight (g)	Total Length (mm)	Girth (mm)	Dorsal Base Length (mm)	Sex	Release Location
47	380	610	105	32	F	Upstream
48	217	520	90	13	M	Downstream Right
49	313	550	95	15	F	Downstream Left
50	418	670	109	20	M	Downstream Right
51	372	628	105	32	M	Downstream Right
52	377	606	113	20	F	Downstream Left
53	372	611	115	15	F	Downstream Left
54	325	616	96	25	F	Upstream

Figure 6. Aerial photograph of release locations of radio-tagged adult Pacific lamprey released in the vicinity of Wanawish Dam on March 30, 2011.

Movements

Six of the eight radio-tagged Pacific lampreys (75%) eventually moved upstream, including 4 of the lamprey released below the dam and both that were released above the dam. Two of the lamprey released below the dam did not move and evidence indicated both were depredated, most likely by otters. Five of the 8 (63%) approached one or more of the dams. The number of days between release and first approaching one of the dams ranged between 2.2 and 42.5 days. Two of the lampreys that approached Wanawish Dam did not pass the dam but instead moved back downstream; one of these exited the Yakima River. The movements of tagged lamprey at each dam are described in the following sections.

Wanawish Dam

First Approach - Tagged lamprey approached Wanawish Dam from April 1 to May 4, 2011 (Table 2). All four lampreys were first detected at the left bank station on the downstream aerial antenna. Three of these fish were recorded on the right bank station within 3 hours as they moved from left to right along the dam. The fourth was recorded on the left bank station for nearly 20 days before it moved close enough to the right bank station to be detected.

Table 2. Wanawish Dam approach and residence data: first and last downstream detection dates and number of days that adult radio-tagged Pacific lamprey resided below the dam during spring, 2011.

Code	1st Station Detected	1st Downstream Detection Date	Last Downstream Detection Date	Days	Enter Fishway?
48	Left bank	04/10/2011 21:29	05/19/2011 14:41	38.7	No
50	Left bank	04/01/2011 20:36	04/08/2011 11:48	6.6	No
51	Left bank	04/01/2011 22:14	04/03/2011 05:43	1.3	Yes
53	Left bank	05/04/2011 21:52	05/05/2011 07:38	0.4	No

Below Dam Residence- The residence time at Wanawish Dam before entering the fishway was 1.3 days for code 51 (Table 2). Codes 53 and 48 approached Wanawish Dam but then moved back downstream and had residence times of 0.4 and 38.7 days, respectively. Code 50 approached the dam and had a residence time of 6.6 days before the tag was located, but not recovered, along riprap in a hole that appeared to be a mink den, indicating the lamprey was likely depredated or scavenged.

Shortly after first arriving at Wanawish Dam codes 48 and 50 were detected on the left bank fishway entrance antenna but neither entered the fishway. Both lampreys resided near the face of the dam until they moved to the other bank. Shortly after code 50 moved to the right bank it was detected on that fishway entrance antenna and may have briefly entered the fishway before it moved a short distance downstream, where it was detected by the aerial antenna until depredated. Code 48 remained near the face of the dam while detected on the right bank, particularly on the right edge of the dam face, until it moved downstream and ultimately exited the Yakima River.

Fishway Passage- Only one of the four lampreys definitely entered a fishway at Wanawish Dam (Table 3). The right bank fishway was used by lamprey code 51 to pass upstream of the dam. It took 19 minutes for this fish to navigate from the entrance antenna to the exit underwater antenna, but it then remained in the exit pool of the fishway for several days. The total time from entrance to exit of the fishway was 6.3 days. During this time, the exit trash rack was not cleaned and had accumulated a considerable amount of debris which may have affected the behavior of the lamprey in the fishway. Stream discharge was high during the time code 51 resided in the ladder and could also have altered its behavior.

Table 3. Wanawish Dam fishway data: dates of entry, exit and total time in fish ladder for radio-tagged adult Pacific lamprey during spring, 2011.

Code	Fishway	Enter Ladder	Exit Ladder	Time in Ladder
51	Right	04/03/2011 05:43	04/09/2011 13:41	6.3 d

Above Dam Residence- After exiting the fishway at Wanawish Dam, code 51 entered the right bank Columbia Irrigation District Canal, where it stayed just downstream of the canal entrance for 22.2 days. It then continued migrating upstream. Code 47, released upstream of the dam, moved upstream and was last located near Benton City at rkm 38 on May 4.

Prosser Dam

Two tagged lampreys were detected at Prosser Dam. Code 54 took 42.5 days to reach Prosser Dam after it was released upstream of Wanawish Dam. However, code 54 remained near its release location through at least May 4 so its actual travel time to Prosser Dam was less than 8 days. Code 51 was released downstream of Wanawish Dam and after passing that dam and leaving the canal, took 4.2 days to reach Prosser Dam.

First Approach- The two lampreys that approached Prosser Dam were detected on May 6 and May 12, 2011 (Table 4). Code 51 was first detected on the left station and code 54 on the center station.

Table 4. Prosser Dam approach and residence data: first and last dates of detection and number of days that radio-tagged adult Pacific lamprey resided below the dam during spring and summer, 2011.

Code	1st Station Detected	1st Downstream Detection Date	Last Downstream Detection Date	Days	Enter Fishway?
51	Left	05/06/2011 00:13	07/25/2011 23:25	80.9	Yes
54	Center	05/12/2011 01:14	06/28/2011 03:06	47.1	Yes

Below Dam Residence- The residence times at Prosser Dam before passing a fishway were 47.1 and 80.9 days (Table 4). Both lampreys were detected on downstream aerial antennas and at entrance antennas several times before navigating a fishway. Movements along the entire length of the dam occurred, but both lampreys resided the majority of the time near the left bank, where flow over a notch formed more white water than along the rest of the face (Figure 7).

Figure 7. Whitewater area where two adult radio-tagged Pacific lampreys were usually located during the day while residing below Prosser Dam during spring and summer, 2011.

Code 54 was detected outside the entrances to all three fishways on multiple occasions, indicating it was exploring back and forth across the face of the dam and near the ladders before it finally passed. It was first detected at, but did not enter, the right entrance of the center island fishway on May 13, and then during the next several weeks, it was detected several times outside both side entrances to the center ladder, outside the left island fishway entrance, and outside the right bank fishway high water entrance. On June 20, it entered the left fishway and was briefly detected on the underwater antenna in pool number 4 before it descended. On June 23, it briefly entered the right bank fishway high water entrance pool and on June 28, it re-entered that entrance and ascended the ladder.

Code 51 was detected at the left fish ladder entrance of the center island fishway on May 19 but did not enter the ladder. It was also detected at the entrance to the left island fishway on June 20 but it did not enter that ladder until July 25, when it finally passed. Code 51 was never detected at the right bank fishway.

Fishway Passage- Lamprey code 54 entered the right bank fishway on June 28 and navigated the ladder in 21.9 hours but was not recorded by the video camera in the counting window. Lamprey code 51 entered the left fishway on July 25 and navigated the ladder in 3.5 hours (Table 5) where it was recorded by the video camera in that counting window.

Table 5. Prosser Dam fishway data: dates of entry and exit and total time in the fish ladder for radio-tagged adult Pacific lamprey during summer, 2011.

Code	Fishway	Enter Ladder	Exit Ladder	Time in Ladder
54	Right bank	06/28/2011 03:06	06/29/2011 01:02	21.9 h
51	Left	07/25/2011 23:25	07/26/2011 02:58	3.5 h

Above Dam Residence- Both lampreys quickly moved upstream after passing Prosser Dam and were only briefly recorded on the upstream antennas. Code 51 migrated to Sunnyside Dam, but the location of code 54 could not be determined after it passed Prosser Dam.

Untagged lampreys at Prosser Dam- Eight untagged and one tagged Pacific lamprey were recorded by the video cameras at the counting windows in the fishways at Prosser Dam between May 11 and September 10, 2011 (Figure 8). Code 54 was not observed passing the counting window and was not counted.

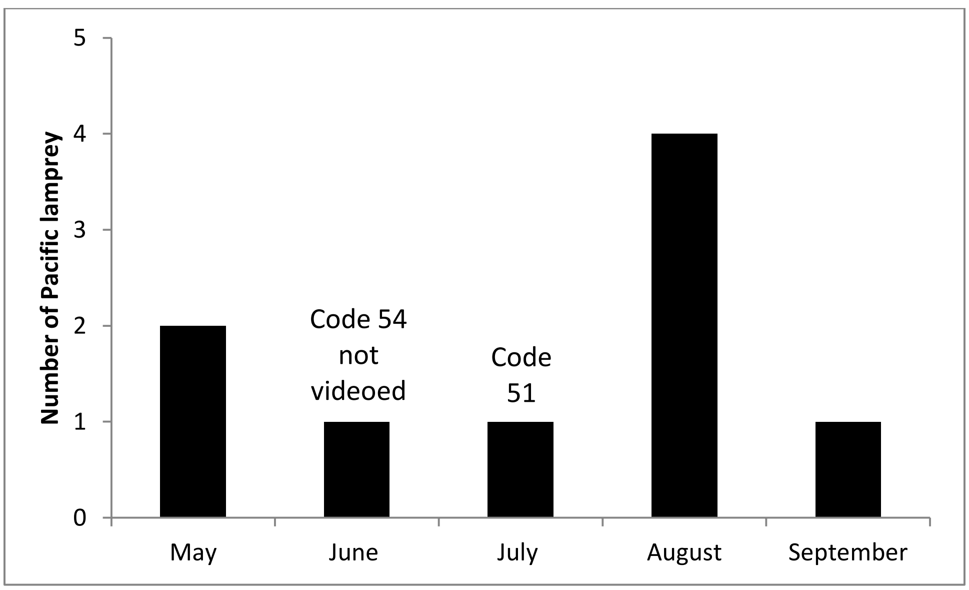

Figure 8. Video counts of adult Pacific lamprey at Prosser Dam, May - September, 2011.

Sunnyside Dam

First Approach- Lamprey code 51 approached Sunnyside Dam on August 2 at 21:47. It was first detected on the aerial antenna on river left of the center island fishway station. During the next two hours it moved from the left side of the island fishway to the right side and then back to the left side.

Below Dam Residence- Code 51 resided at the downstream face of Sunnyside Dam near the corner formed by the left side of the center island and the dam. It was detected for 34 days until the transmitter battery died on September 5, 2011.

Fishway Passage- Lamprey code 51 did not enter the fishway before the battery died.

Above Dam Residence- Code 51 was not detected passing Sunnyside Dam before the transmitter battery died.

Diurnal Period of Movement

Movements of Pacific lamprey between fixed stations occurred almost exclusively at night (Figure 9). All initial approaches to the dams and movements into the fishways were made during night. Movement out of the fishway at Wanawish Dam by code 51 was done during daylight hours. Codes 48 and 53 moved back downstream from Wanawish Dam during daylight.

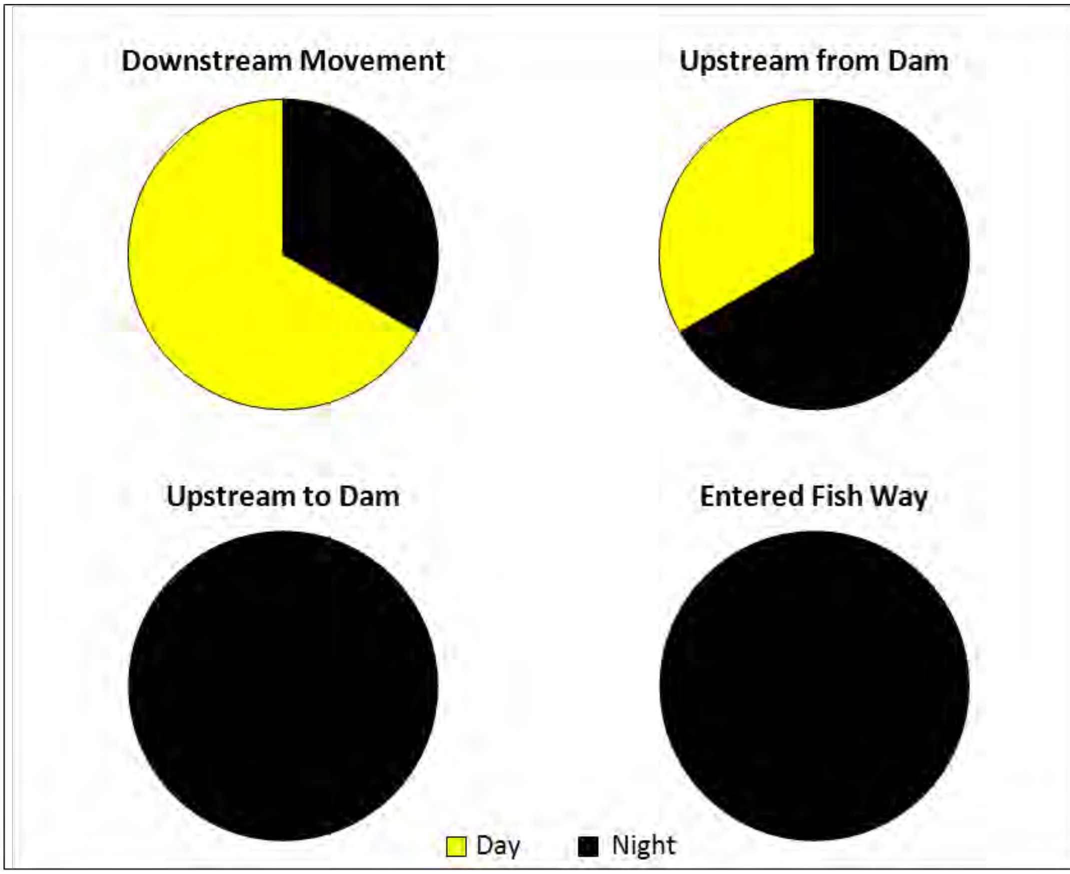

Figure 9. Diurnal periods that adult radio-tagged Pacific lamprey were active during downstream movement, upstream movement, and entry into fishways during spring and summer, 2011.

Migration Rates between Stations

After passing a fish way and leaving a dam, code 51 moved very quickly to the next dam. It took 4.2 days to migrate the 46.7 km from Wanawish Dam to Prosser Dam for an average migration rate of 11.11 km/d. From Prosser Dam to Sunnyside Dam, a distance of 91.4 km, it took 7.91 days for an average migration rate of 11.56 km/d. Only one lamprey (code 48) moved downstream from Wanawish Dam past the RG station and it took 26.49 days to travel that 22.5 km, for an average rate of 0.85 km/d.

Temperature

The temperature loggers were deployed at the three dams and began recording data on June 23, 2011. At Prosser Dam, mean daily stream temperatures ranged from 15.5 ºC to 17.7 ºC during the time code 54 resided at the dam and ranged from 15.5 ºC to 22.2 ºC when code 51 resided there. At Sunnyside Dam, mean daily stream temperatures ranged from 16.1ºC to 18.6 ºC during the time code 51 was present.

Discharge

Stream discharge appeared to influence the movements of radio-tagged lampreys (Figure 10). During high discharge periods, lampreys resided below the dams. Code 51 moved upstream through the fishways and migrated between the dams when discharge was low. Code 54 remained near its release site upstream of Wanawish Dam until it moved upstream during low flow on May 4, prior to peak flows in spring. The two lampreys (codes 48 and 53) that did not pass Wanawish Dam instead moved downstream when discharge increased to peak flow.

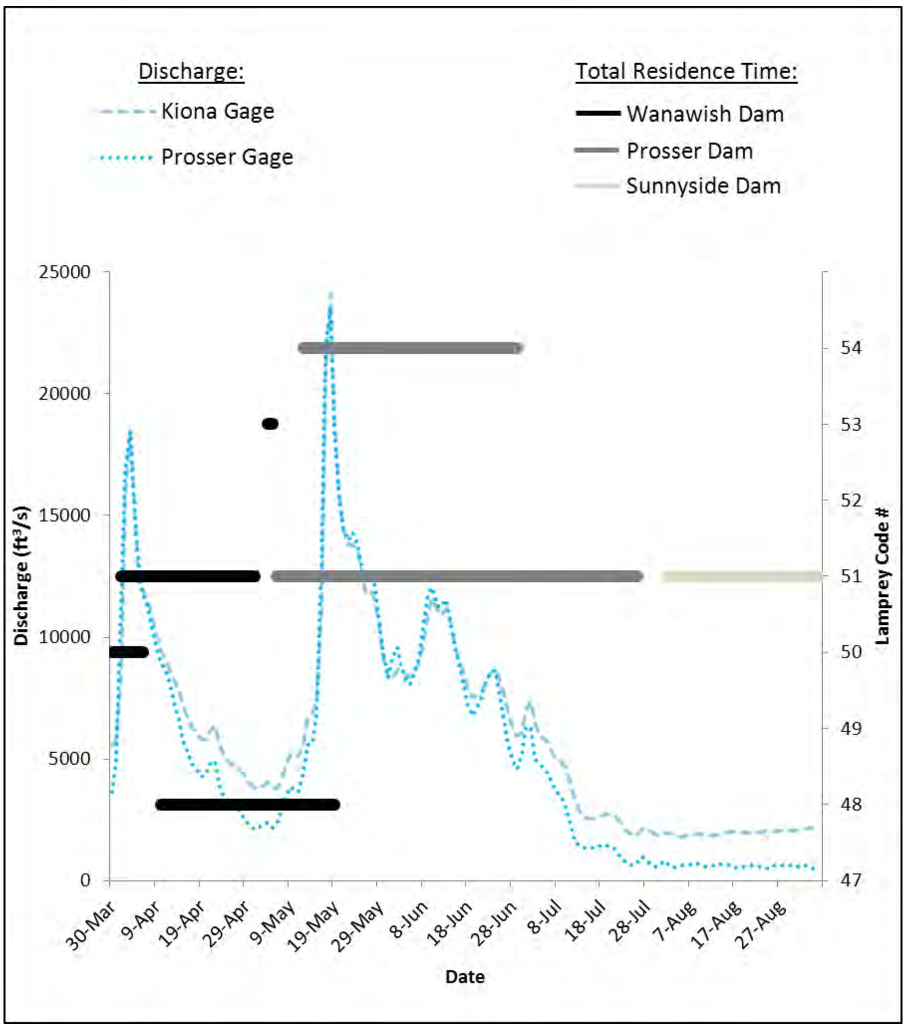

Figure 10. Chart showing the relationship between stream discharge and total dam residence time of radio-tagged adult Pacific lamprey at diversion dams in the lower Yakima River during spring and summer, 2011.

Discussion

The spring release of tagged Pacific lamprey was the beginning of our study of their movements at diversion dams in the lower Yakima River. Fewer lampreys were available for tagging than planned, but this first phase served as a successful pilot to guide future release and monitoring strategies, and demonstrated that our study design is adaptive. Although just 8 lampreys were released at only one dam, a considerable amount of information was obtained. Most of the lampreys moved upstream, suggesting that the behavior of lampreys collected in the Columbia River and released in the Yakima River is similar to the behavior of lampreys voluntarily entering the river. The telemetry arrays at the fixed stations were proofed and we verified that accurate, useful information was recorded. The initial telemetry data allowed us to tune the arrays and add additional antennas where needed. The apparently high predation rate at Wanawish Dam indicates we need to release a greater number of tagged fish at each site than we had planned. The paired downstream/upstream releases of tagged lamprey provided both test and control treatments of their movements at the dam but the low passage rate, combined with the relatively high predation rate, indicated we need to release more lampreys. For the fall release, we have 42 transmitters available and plan to release 21 tagged lampreys each at Wanawish and Prosser dam, with a design of 16 released below each dam and 5 above.

Our spring-release sample size was small, but the initial results of Pacific lamprey behavior at the lower Yakima River diversion dams allow a preliminary comparison with other telemetry studies. Keefer *et al.* (2009) and Moser *et al.* (2005) found that less than 50% of radio-tagged Pacific lampreys successfully pass a hydroelectric dam on the lower Columbia River. Main-stem Columbia River dams are much larger and more complex, but our results show that the small diversion dams on the Yakima River are similarly impeding the migration of Pacific lampreys. Only 1 of the 4 Pacific lampreys that approached Wanawish Dam successfully passed upstream. At Willamette Falls Dam on the Willamette River, a lower Columbia River tributary, Clemens *et al.* (2011) also found a passage rate of less than 50%. Interestingly in our study, both lampreys that approached Prosser Dam successfully passed it, but we do not know what the impacts of the long delay was on their reproduction. Spawning areas and timing have not yet been located or described in the Yakima River.

Video counts in the fishways at Prosser Dam indicate that Pacific lamprey pass upstream primarily during the spring, mostly in April and May, and secondarily during the late summer and fall. Our tagged lamprey arrived at Prosser Dam in May but did not successfully pass the dam until June and July. Only one untagged lamprey was counted during June, but lamprey code 54 was not videoed or counted when it passed through the right bank fishway on June 28th. Apparently this lamprey found a route in the ladder that bypassed the video area and indicates that some lampreys are passing the fishways at the dam without being detected and counted.

Counts from this year to date showed passage at Prosser Dam occurred between the months of May and September. In most years since counting began in 2002, the majority of lamprey passed in April and none passed in late June and July. The later summer passage by both tagged and untagged fish in 2011 may be due to the higher than normal discharge that occurred; it also could be due to a source and/or tagging effect in our study fish.

We modified our original telemetry station design due to environmental factors as well as movements of the lamprey. The discharge this year was higher than normal and caused the AC power to be turned off at the diversion dams for safety reasons. Our receivers therefore lost power, so we added solar panels as backup in the event of another outage. We also added an additional receiver and aerial antennas at Prosser Dam to increase detections of movements along the river left face of the dam where the lamprey held for extended periods of time. We plan to modify the attachments and raise the station boxes to ensure they will not be flooded during high water events in the future. We found that truck surveys had low detection rates because the distance of roads from most of the river usually exceeded the detection capability of our mobile system. We also found that boat tracking was inefficient and too labor intensive to employ for regular surveys. Therefore, we will explore the feasibility of aerial surveys to track radio-tagged lampreys between the dams, and in conjunction with boat surveys, determine overwintering and spawning areas.

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APPENDIX D

Assessment of Lamprey Presence in Irrigation Diversions and Canals in the Yakima Basin

Confederated Tribes and Bands of the Yakama Nation
Department of Natural Resources, Fisheries Resources Management Program

Yakama Nation Pacific Lamprey Restoration Project

Assessment of lamprey presence in irrigation diversions and canals in the Yakima Basin

Prepared for:

Bureau of Reclamation

Annual Update Preliminary Report

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Introduction

Historically, Pacific lamprey were found throughout much of the Columbia River Basin (Kan 1975; Hammond 1979; Vella et. al.1999). Populations have drastically decreased over the last 50 plus years due to a variety of factors, including but not limited to dam passage, habitat degradation, and potential entrainment of juveniles into irrigation diversion canals and ditches.

There are two known species of lamprey in the Yakima subbasin. Pacific lamprey (*Entosphenus tridentatus)* are an anadromous species, spending part of their life cycle in both the freshwater and ocean environments. The other species is the Western brook lamprey (*Lampetra richardsoni)*, a resident lamprey whose life cycle remain solely in freshwaters. Unfortunately, resource managers know less about these species than most other fish species, both native and non-native, within the basin. To the Yakama people Pacific lamprey are vital to their culture and traditions, both as a staple and as a medicine.

Local regional agency biologists have suspected that tributary irrigation dams may create passage barriers for upstream migrating adults and may also entrain juveniles into irrigation ditches as they migrate downstream. As a result, the Bureau of Reclamation (Reclamation) and the Yakama Nation (YN) are working together to evaluate potential issues associated with Pacific lamprey movement past irrigation diversions in the Yakima River Basin. In this report, we focus primarily on potential issues associated with juvenile entrainment into diversion ditches through the existing fish screens.

Existing fish screens were designed to keep salmonids and other larger fish from entering the irrigation canal systems. However, it has become increasingly evident that other fish species, such as lamprey, may be moving through some of these screens. Currently, there is no empirical information to indicate the magnitude of this potential issue. Preliminary tudies by the YN within the Yakima River Basin over the past two years (2010 and 2011) were designed to be exploratory in nature, with the intention to simply identify, in a qualitative context, if lamprey were present in various canals, and, if so, which species are present. Much of this "presence / absence" information has been established and future surveys will be designed to address these issues in a more quantitative manner.

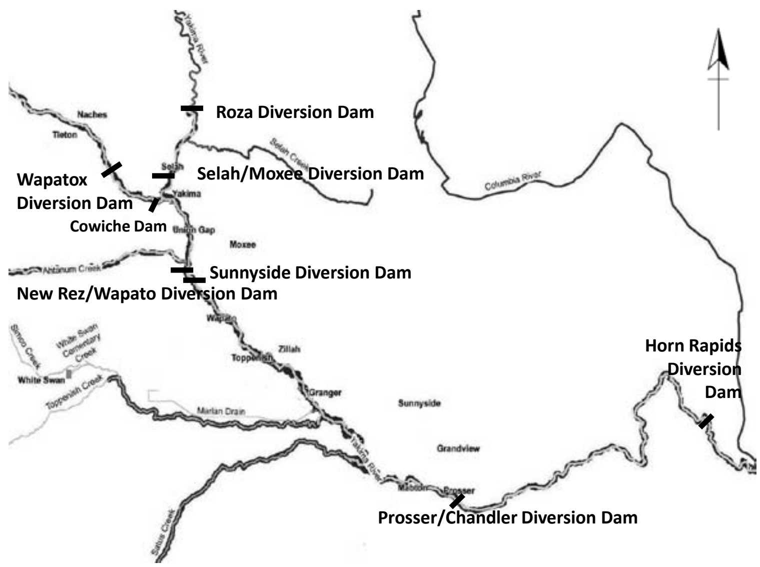
In 2010, the YN performed preliminary surveys in front of and behind diversion screens at the Prosser/Chandler, Sunnyside, Wapato/New Rez, Selah/Moxee, and Roza irrigation diversions. The results indicated that larval lamprey were present behind some screens, which justified additional surveys to be conducted in the 2011 field season. In 2011, eight diversions and four canals were surveyed from Horn Rapids dam up to Roza Dam of the Yakima River. These surveys were coordinated by YN and Reclamation staff during the dewatering events at each of the canals. The intent of these surveys has been to obtain baseline information addressing two basic questions:

1. are juvenile lampreys found behind diversion screens, and if so,
2. which canals contain the greatest number of lamprey?

Over the next two or three years, the YN will continue to survey all major canal systems in the Yakima River Basin. These surveys will help determine relative abundance, size/age classes, distribution, and species composition of lamprey in various canals.

Purpose and scope

The purpose of these surveys is to determine the extent that juvenile lampreys are found behind the fish screens within various irrigation canals. Upon verifying presence, we are interested in 1) estimating how many lamprey of each species are entering the canals each year, 2) understanding how lamprey are distributed in the canals and 3) what age groups are present. Over the next few years, additional surveys will be performed to estimate the number of juvenile lamprey that are behind these screens and to determine how they are getting behind these screens.



Study Area

Figure 1 – Overview of the study area and major irrigation diversions dams (indicated by solid bars) in the Yakima River Basin.

The study area contained major irrigation diversion canals within the lower Yakima River Basin (Figure 1). For the 2010 and 2011 field season, these include the following diversions: Horn Rapids, Prosser/Chandler, Sunnyside, Wapato/New Rez, Selah/Moxee, Roza, Cowiche, andWapatox.

Yakima River

- Horn Rapids (Wanawish) diversion is in Benton County at river mile 18 from the Columbia River.
- Prosser/Chandler diversion is in Benton County at river mile 47 from the Columbia River at Prosser, Washington. Chandler canal entrance is on the left bank of Prosser dam.
- Sunnyside Dam and diversion is location in Yakima County at river mile 103 on the left bank and the canal runs 60 miles eastward to Prosser.
- Wapato/New Rez diversion is located in Yakima County at river mile 104 upstream of Sunnyside diversion and is on the right bank approximately 1.4 miles southwest, and north-west of Parker.
- Selah/Moxee diversion is located in Yakima County, and the water is diverted from the mainstem Yakima near the township of Selah.
- Roza dam and diversion is located in the Yakima County at river mile 127.8 on the right bank about 10 miles north of Yakima.

Naches River

- Cowiche Creek diversion is located in Yakima County approximately 3.4 miles west-southwest of Yakima, and 6 miles west of Cowiche.
- Wapatox diversion is located in Yakima County about 7.4 miles upstream from the Yakima River and 0.5 miles below Tieton River near the township of Naches.

Methods and Materials

Surveys took place from late October to mid November for both 2010 and 2011 seasons after coordinating with Reclamation staff on planned dewatering periods. Roza, Selah/Moxee, Wapato/New Rez, Sunnyside, Cowiche, Prossor/Chandler and Horn Rapids were sampled in the 2010 and 2011 field seasons with the addition of Wapatox in 2011.

Initial locations of sampling sites were determined using Google earth software based on the likelihood of diversion canals containing Type I habitat[1] (Slade et al. 2003). Actual sample locations were modified based on "on the ground" conditions. Sampling at sites began from the

[1] Type I habitats are those containing significant portions of mud/sand mixture with detritus materials preferred for rearing juvenile lamprey.

downstream side working upstream to ensure that water would not become turbid during sampling. Type I habitat and secondly Type II habitats were surveyed within the sampling sites. At each sample site, a 7.5-m^2 plot was measured, and a backpack electrofisher model unit AbP-2 specialized specifically for lamprey (Engineering Technical Services, University of Wisconsin, Madison, Wisconsin) was used to determine if lamprey larvae were present. The electrofishing unit delivered 3 pulses per second (125 volts DC) at 25% duty cycle, with a 3:1 burst pulse train (three pulses on, one pulse off) to remove larvae. Surveys were done in water <0.1 meter in depth. If any lamprey were found during the first 90-second pass, we continued with two more 90-second passes consecutively. If more fish were found, electrofishing extended further in the canal to initiate a fish salvage effort. Following collection, random subsamples of larvae were anaesthetized in MS-222 at 50 mg/L (tricane methanesulfonate). If possible, larvae were identified to species using the caudal ridge pigmentation assessment (Meeuwig et al. 2004; Goodman et al. 2008; Lampman and Streif 2008) with a 20X Nikon Field Microscope. Our sampling effort concentrated on the capture of each fish observed, and these fish were transferred into buckets and later into aerated coolers to be transported back into the mainstem of the Yakima River.

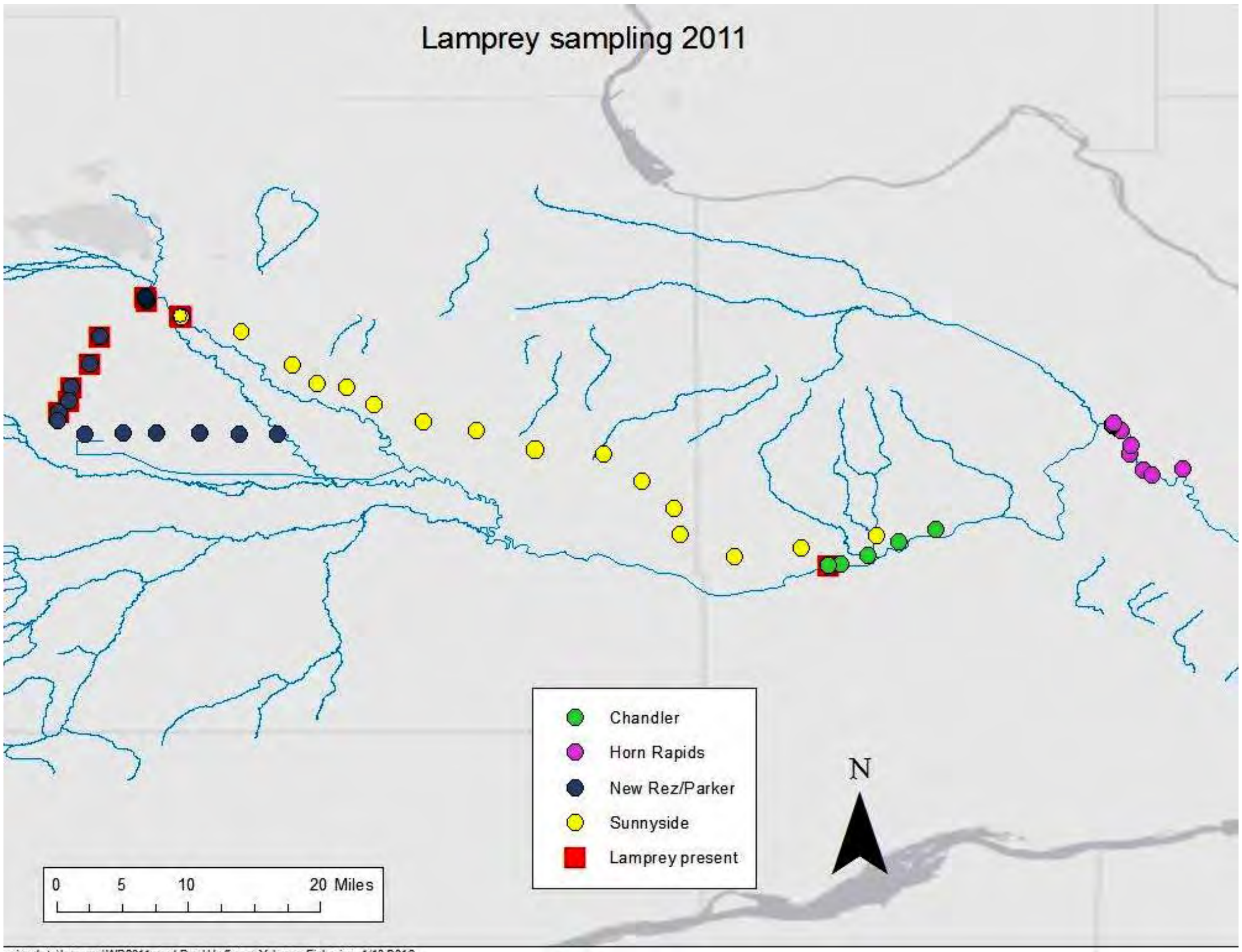
Results

Both 2010 and 2011 field surveys observed juvenile lamprey above and below fish screens in various canals, though none of these were determined to be Pacific lamprey. A total of 526 and 248 lamprey, either Western Brook or unknown species, were caught in front of the screens from various diversions in 2010 and 2011, respectively, and 1901and 584 lamprey were caught behind the screens during the 2010 and 2011 surveys, respectively. Table 1 summarizes these results.

TABLE 1. - Number of lamprey caught at eight diversions during the 2010 and 2011 field seasons.

YEAR Diversion	**2010** Front	**n = 2427** Behind	**2011** Front	**n = 832** Behind
YAKIMA				
Horn Rapids	0	0	0	0
Prosser/Chandler	0	0	0	0
Sunnyside	0	1292	0	224
Wapato/New Rez.	325	358	83	360
Selah/Moxee	0	0	38	0
Roza	0	24	29	0
NACHES				
Cowiche	201	227	0	0
Wapatox	NA	0	98	0

In 2010, most samples were taken near each of the fish screens within the various diversions. However, in 2011 a greater emphasis was placed on understanding if juveniles were moving lower into the canal systems. Initial findings suggest that most lamprey are found in the upper portions of these irrigation canals. This question will continue to be investigated in the 2012 survey season. Figure 2 (below) shows the 2011 sampling sites in the four major diversions in the lower Yakima River. **C**olor dots indicate each of the individual canals and specific locations of sample sites from Horn Rapids up to Roza. The sites that had lamprey are indicated in red boxes in this Figure.



c:\avdata\lamprey\WP2011.mxd Paul Huffman, Yakama Fisheries, 1/13/2012

Figure 2 - Overview of the 2011 sample sites of diversions and lamprey distribution within the canals.

Site-Specific Notes

Horn Rapids canals are located on both the left and right banks of the Horn Rapids Dam. In 2010 two sites on each side of the dam screens were sampled. In 2011, we sampled same areas but extended down the canal and covered 11 sites. Habitats sampled were in front and behind the trash racks, front and behind the screens composing of Type I and II habitats, with cut off banks. As we moved down canal, habitats consisted of hard substrates composed of gravel, cobble, boulders, woody debris, aquatic grasses, clay and some sand deposits. There were small amounts of garbage, the water was clear and had an average temperature of 7.4° C. We did find suitable habitat but no lamprey were observed at Horn Rapids.

Prosser/Chandler is located in Prosser Washington on the Yakima River. There were eight areas sampled both in front and behind the trash racks in all depositional areas. The habitat was primarily made up of Type I and II habitat with loose sand on the subsurface within the diversion. Below the diversion behind the screens, the same type of habitats continued for approximately 400 meters. Beyond this, the canal is concrete channel with small sections of standing water habitat. Once we completed this diversion survey, we continued to move down stream and sampled sites every 2 miles of the 12-mile canal. No lamprey were observed at Prosser.

Sunnyside is located off the old Yakima hiway just NE of Parker Washington. A total of 18 sites were sampled from below the canal to the outlet NE of Sunnyside Washington. This canal water supply is located on the left bank of the Yakima River. Habitat from the diversion to the screens is made up of large cobble,sand and mud. We observed several fish swimming in front of the screens. At the diversion itself the substrate is accumulation of Type I organic mud and sand, ideal for larval lamprey. Once we began electrofishing there were large numbers of lamprey emerging from the substrate almost continuously. This was the second season of sub sampling and both years had abundant larval lamprey and juvenile fish of other species behind the screens. All lamprey were found behind the screens.

Wapato/New Rez is located just off hiway 97 just NW of Parker Washington. A total of 16 sites were sampled from the screens to the outlet of this canal. Diversion sections sampled were made up primarily of Type I habitats both in front and behind the screens. The trash racks were sampled but not many larval lamprey were caught; the majority of the larval lamprey were captured in front and behind the screens. The substrate consists of riffle wave substrates of sands, organic, and mud habitats (Type I). Samples were taken down the canal every 2 miles where 14 larval lamprey were captured about 12 miles down the canal near the township of Harrah, Washington. The habitat was patchy with armored substrates of gravel, cobble, mud and sand mix.

Selah/Moxee is located on private property and the water diverted is from the Yakima River near the township of Selah, Washington. The annual dewatering period is short due to the removal of the silt deposits each year. Samples were taken in good preferred larval Type I habitat. Organic materials were present throughout these areas and 38 lamprey were caught and transported to the Wapato Reach.

Roza dam is located in the Yakima canyon reach on the Yakima River. At this site a total of two sample areas were examined behind the drum screens where we sampled the small deposition of Type I habitats. The majority of this area is made up of hard clay substrates with gravel and cobble mixed in, but several larval lamprey were observed.   In 2011, 29 lamprey were collected in front of the screens with none behind, but in 2010 24 were from behind the screens with none in front. Larval lamprey were sampled, ranging from young of the year up to fish that were transformers into sub adults. Within the substrates, many aquatic animal and bird tracks were observed such as otters, raccoons, coyotes and/or dog prints.

Cowiche creek diversion sample area location is just upstream where it enters the Naches River. In 2010, the 400 meter section had larval lamprey near the outlet, and as we moved up stream to the inlet we caught more fish. In 2011 no lamprey were caught. The habitat is made up of fine organic materials of leaves, detritus materials with small woody debris intertwined in Type I habitats.

Wapatox diversion is located near the township of Naches, Washington. The system supplies water from the Naches River. Two sites were sampled within the diversion where some woody debris with sand, mud, and sedge grass were found to hold a few lamprey in front of the screens. We were unable to completely sample in front of the trash racks due to dangerous conditions, but did find patchy suitable habitat to survey and found larval lamprey in two different areas.

Discussion

These initial surveys are our first attempt to assess the presence and distribution of lampreys during the annual dewatering of these canals. These surveys are preliminary but indicate that Western brook lamprey and potentially Pacific lamprey are getting behind certain screens (e.g. Sunnyside, Wapato/New Rez, and Roza), although it is not yet clear how they are getting past the screens. Lamprey of various size classes are found both in front of and behind these screens, suggesting some lamprey actually survive the dewatering period and rear in portions of the canal throughout the entire year. Alternatively the screen system may actually allow multiple age classes to pass into the canal.

For example, in 2010, length and weights measurements were taken on random samples of 240 juvenile lamprey from the Wapato/New Rez sites. Figure 4 below illustrates the length classes that were found. This information likely indicates that there are several age classes in these systems ranging from fish less than 40 mm (likely young of the year) to transforming individuals greater than 100 mm. The entire subsample of 240 individuals greater than 50 mm were identified as either Western brook lamprey or unknowns. There were no Pacific lamprey positively identified during the entire sampling time.

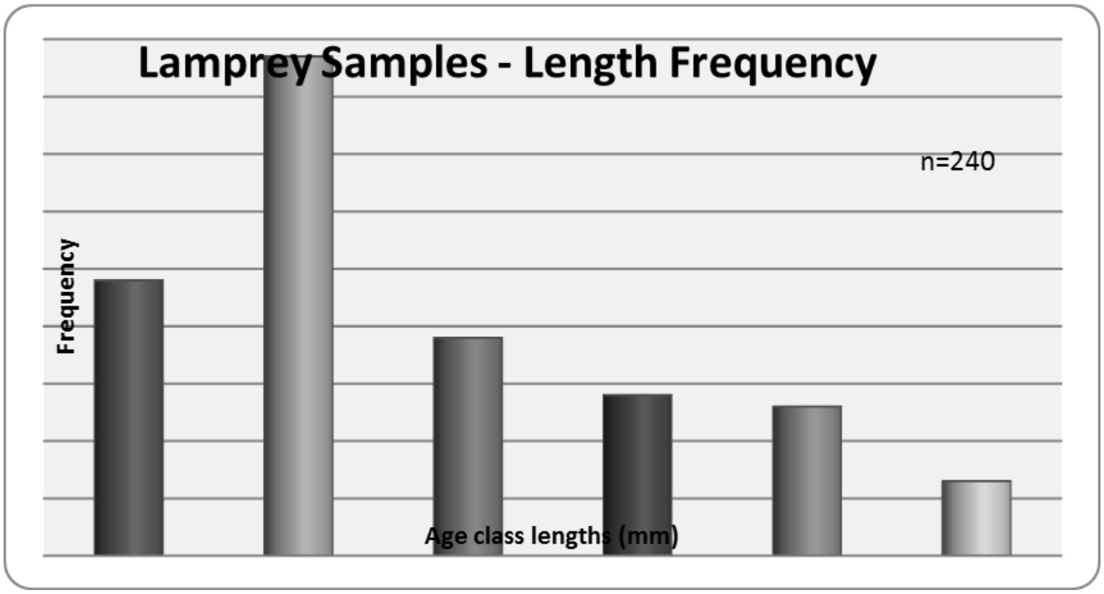


Figure 2 - Length Frequencies of juveniles lamprey found at diversion at Wapato/New Rez 2010.

One of the key problems is the difficulty in confidently identifying lamprey species in the field. Determination between Pacific and Western brook lamprey at smaller size classes (approximately <50 mm or smaller) is very difficult. Genetic samples could be obtained to make this determination. The presence of Western brook lamprey behind screens indicates the screens may not be an effective barrier to prevent entrainment of lamprey, but the effect on Pacific lamprey is not known. There is currently little documented reproduction of Pacific lamprey in the Yakima River Basin and therefor likely a low chance of Pacific lamprey juveniles in the river and subject to entrainment. As Pacific lamprey propogation, translocation, and reintroduction efforts progress, there are likely to be more of this species' juveniles in the river. Our sampling approach was appropriate for establishing preliminary baseline data at this time. In future years, additional studies will be conducted to determine a better estimate of relative abundance to estimate entrainment through the screens and to explore the mechanisms by which lamprey are entering into these canals.

Future Recommendations

1) Surveys should continue in future years to determine presence and relative abundance of juvenile lamprey and specific age classes found within all major canal systems in the Yakima River Basin. Given the substantial number of canals within the Yakima Basin and the overall extent of these systems, this will require greater efforts and time to obtain this important information in a timely manner.

2) Methods should be developed to determine how juvenile lamprey are entering into the canal system with a focus on identifying if and how different age classes are moving past the existing screens. It is likely that lamprey are overwintering in some of the canal systems. We recommend that future surveys examine specific areas within the canals that contain water throughout the winter to evaluate this potential.

3) Entrainment studies using other methods such as fyke nets could target specific canal headworks to better estimate entrainment, with results of these initial surveys helping to prioritize which canals to study further. As Pacific lamprey juveniles become available, targeted experimental releases in proximity to canals followed by sampling via these nets could also help evaluate entrainment potential of Pacific lamprey.

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APPENDIX E

Response of Pacific Lamprey Ammocoetes and Macropthalmia to Several Physical and Behavioral Guidance Devices

Response of Pacific lamprey ammocoetes and macropthalmia to several physical and behavioral guidance devices

Progress Report of Science and Technology Program Proposal 0035

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Introduction

Pacific lamprey *Entosphenus tridentatus* populations in the Columbia River basin have declined substantially in recent years and although the species is not listed under the Endangered Species Act, it is the subject of much research by federal, state and tribal agencies. Pacific lamprey are culturally important to Native Americans; they were historically a source of food and medicine and even today figure prominently in Native American culture. The substantial decline of Pacific lamprey populations has diminished to some extent the cultural practices of some Native American tribes. Pacific lamprey also provide numerous ecologically important benefits to aquatic ecosystems, such as a food source for juvenile salmon, birds and mammals, and returning adults historically were a source of marine-derived nutrients that helped sustain aquatic, riparian and terrestrial ecosystems (Beamish 1980, Lewis 2009). Adult Pacific lamprey also provided an alternative food source for California sea lions in the lower Columbia River, thereby reducing predation on returning adult salmon and steelhead.

Irrigation and other water diversion projects are commonplace in the numerous tributaries of the Columbia River basin. The Bureau of Reclamation as well as other federal and state agencies and local irrigation districts own and operate water diversion projects in Columbia Basin tributaries. Historically Pacific lamprey adults spawned and juveniles reared in these fresh water tributaries. There is the potential that during high flow events, juvenile Pacific lamprey rearing in the fine sediments of these tributaries could be dislodged from the substrate and entrained into irrigation and other diversions and lost to the population. Because of the substantially reduced population of Pacific lamprey in the Columbia Basin tributaries where Reclamation operates water diversion projects, it was deemed necessary and important to investigate methods to reduce or eliminate entrainment of juvenile Pacific lamprey into canals and keep them in the river and in suitable rearing habitat. Juvenile Pacific lamprey that were guided away from water diversions would be spared from entrainment into an irrigation canal. They would have an opportunity to seek out lower water velocity areas downstream and resume their filter feeding rearing strategy.

A short description of the early life history of Pacific lamprey is relevant here, since it sets the stage for this research project. The early life history stage of the Pacific lamprey is somewhat complex. After hatching in the spring, the young Pacific lamprey ammocoetes drift downstream to suitable rearing habitats such as backwater areas and pools that generally have low water velocity (Streif 2009) and a silty sandy substrate into which the ammocoetes burrow and feed by filtering diatoms and other small organic material (Simpson and Wallace 1978). During high flow events that disturb or disrupt the substrate, the juvenile lamprey can be displaced downstream. When water velocity decreases and conditions become favorable, they again burrow into the substrate and resume filter feeding. In basins where water is diverted for irrigation or other uses, juvenile Pacific lamprey that are passively moving in the higher flow could be diverted into the canal, and if not returned to the river through a juvenile fish bypass system, but instead get passed the fish screens and settle out in the lower velocity conditions in the canal, they could become lost to the population when the irrigation diversion ceases operation for the season and the canal is dewatered.

After rearing in fresh water habitats for from four to seven years, the juvenile Pacific lamprey undergo a physiological transformation and prepare to migrate downstream in the springtime as macropthalmia. These actively migrating macropthalmia may also be entrained in diverted flows into irrigation canals. The size of the Pacific lamprey at this life stage is generally large enough that they would likely be bypassed back to the river through the juvenile fish bypass system.

The focus of this research project was to evaluate some potential physical and behavioral guidance devices that could potentially reduce the diversion of juvenile Pacific lamprey into canals. We tested a wedge wire screen and woven wire screen. The wedge wire screen met NOAA Fisheries criteria for fry. Woven wire was 4.5-12, or 5/32-inch opening. This size of woven wire screen is commonly used on rotating drum fish screens at juvenile fish bypass systems in the Yakima Basin. We also tested an air bubble curtain similar to that tested in 2009, and a low voltage high intensity light bar array. Lastly we tested a combination of the air bubble curtain and the low voltage high intensity light bar array at night. High intensity lights have been used in some situations to guide fish away from a structure or back to the river (Liter and Maiolie 2002; Königson et al. 2002; Stark and Maiolie 2004; Simmons et al. 2006).

Methods

Test flume—A flume for testing physical and behavioral guidance devices with juvenile Pacific lamprey was constructed by personnel from the Umatilla Field Office, Hemiston, Oregon. The flume is 16-ft-long, 2-ft-wide and 18-inches-deep to provide an operating water depth of about 12 inches and is constructed of 3/4-inch marine-grade plywood (Figure 1). The 2-ft-long head box was formed by three ¼-inch perforated plates installed in slots 12 inches, 18 inches, and 24 inches from the upstream end of the flume that served to diffuse the flow. Three 3-inch-diameter fish introduction tubes on the downstream-most plate were located at the right side, center and left side, centered 5-inches above the bottom of the flume. The right and left tubes were centered 5 inches from each side. Eight feet downstream from the third diffuser plate, the main 2-ft-wide channel was divided into two narrower 1-ft-wide channels with a splitter wall. Grooves were cut into the floor of the flume at the splitter wall at 90, 45 and 30 degrees to serve as anchor points to

Figure 1. Test flume viewed from downstream to upstream, showing 3-inch pumps in the distance, and the wedge wire screen in place at the mouth of the right downstream channel.

accommodate a variety of physical or behavioral guidance devices. The flume design allowed a physical or behavioral guidance device to be placed in front of either channel to evaluate its potential to guide fish away from a simulated irrigation or other diversion and to remain in the river. Two feet downstream in each 1-ft-wide left and right channel was a ramp to control water level in the flume. At the end of each 7-inch-high ramp was a wedge wire screen “fish slide” that sloped down into a fish trap for collecting test fish (Figure 2).

Water from McKay Creek was pumped to the flume using three 3-inch-diameter trash pumps. Water entered the first chamber of the head box through 3-inch-diameter pipes (Figure 3). The three ¼-inch perforated plates provided a more uniform flow in the flume. Two 4-inch and one 3-inch drain pipes in the sump adjacent to the fish traps allowed water to flow back into McKay Creek.

Figure 2. Right channel ramp and fish slide into the fish trap of the test flume.

Figure 3. Photograph of the three ¼-inch porous diffuser plates, water inflow pipes from the three pumps and the right, center, and left fish introduction tubes in the test flume.

Water velocity—Water velocity in the flume was measured with a Swoffer model 2100 flow meter at two flow rates. Velocity was measured on the right side, center, and left side of the flume 2 inches below the surface and 2 inches above the bottom at two transects 1.75 and 6.5 feet downstream from the porous diffuser, at the mouth of each downstream channel, and at the top of the ramp at the junction with the fish slide into the fish trap.

Pacific lamprey ammocoetes—About 500 Pacific lamprey ammocoetes and 50 macropthalmia were provided on the first day of testing by biologists from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) (Figure 4). These fish were held in three 100-quart coolers that contained about 3 inches of Quickrete Play Sand to provide a substrate for the burrowing fish. Water from McKay Creek was pumped into each holding tank at a rate of about 4 L/min. Fish were not fed for the few days they were held and required for testing, but some organic material was likely present in the water pumped from McKay Creek and the ammocoetes may have utilized this material as a food source. A small air pump provided aeration.

Figure 4. A Pacific lamprey ammocoete.

Distribution of Pacific lamprey ammocoetes with no guidance device in place—Ten Pacific lamprey ammocoetes were released through the right, center and left fish introduction tubes at high flow to assess their distribution and recovery in the fish traps downstream.

Wedge wire and woven wire screens—Ten tests of both the stainless steel wedge wire and woven wire screens were conducted with 10 Pacific lamprey ammocoetes. The wedge wire screen met NOAA Fisheries criteria for fry, that is, 0.093 inch wire width and slot width between bars of 0.069 inch (Figure 5). It was mounted vertically and positioned 30° to the flow. Woven wire was 4.5-12, or about 1/8-inch opening (Figure 6). This size of woven wire screen is commonly used on rotating drum fish screens at fish bypass systems in the Yakima Basin. Five tests were conducted with the screen in front of the right downstream channel and five with the screen in front of the left downstream channel. The initial intent of randomly assigning each screen to either right or left position in front of the right or left channel for each of the ten tests was determined to be logistically impractical due to the amount of time necessary to manipulate the screen and reseal it after each changeover.

Figure 5. Wedge wire screen used in the test flume.

Figure 6. Woven wire screen in position in the test flume in front of the right channel at 30 degrees to the flow.

Test fish were introduced upstream into the flume through the fish introduction tube that corresponded to the side where the wedge wire or woven wire screen was positioned. The tests were conducted with the three pumps pumping at maximum capacity, which resulted in a velocity of about 0.85 fps. Two additional tests were conducted with Pacific lamprey macropthalmia with the wedge wire screen positioned in front of the left downstream channel. After fish were introduced into the upstream end of the flume through the fish introduction tubes, they were counted as they passed over the fish slide into the fish trap. When all test fish were accounted for or after five minutes, the pumps were turned off and fish were carefully netted from the fish traps. Because of the high velocity over the fish slide into the fish traps and the location where the fish came down the fish slide, some were occasionally not observed and counted, so the actual count of fish recovered in the fish trap was higher than the visual count. Fish recovered from each trap were held separately, lightly anesthetized with about 80 mg/L of tricaine methanesulfonate (MS-222) and measured for total length.

Air bubble curtain—The air bubble curtain was generated using a Whitewater model TL66 diaphragm air pump (Aquatic Eco-Systems, Inc., Apopka, FL) and a 25-inch length of 1-inch OD, ½-inch ID porous tubing positioned in the 30° groove and secured to the bottom of the flume with three small clamps. The air pump had a maximum output of 2.9 cfm. Clear plastic tubing connected the air pump to the porous tubing. The bubble generator was positioned in front of the right channel in the same 30° slot used to seat the wedge wire and woven wire screens (Figure 7). Several series of tests were conducted. The first two tests were conducted with Pacific lamprey ammocoetes, and the next three with Pacific lamprey macropthalmia. The first test was conducted with the high flow of 0.85 fps. It appeared that the high flow pulled or dragged the upper portion of the air bubble curtain downstream into the channel. The second test was conducted at a lower flow using only the center 3-inch-diameter pump, with a flow of about 0.61 fps. Tests 3 through 5 with Pacific lamprey macropthalmia were conducted at high flow.

After these five tests, the bubble generator was repositioned 6 inches further upstream in an attempt to reduce the bubble curtain from being dragged into the channel by the flow. This required installation of an additional plywood floor to provide a recessed anchor point for the porous tubing air bubble generator, since there was no groove in the floor of the flume at this location. The plywood insert had a tapered upstream edge to maintain a smooth flow pattern in the flume. After two tests the bubble generator and plywood insert was repositioned an additional 6 inches upstream for a total upstream change of 12 inches (Figure 8). With the high flow, three additional tests were conducted. We then reduced the flow and conducted five tests with 10 ammocoetes each released through the right side fish introduction tube with the air bubble curtain in front of the right downstream channel.

Low voltage high intensity light bars—Low voltage high intensity light bars were provided by Ovivo USA, LLC, Salt Lake city, Utah, courtesy of Mr. Kaveh Someah. The light units and their power supply had been used in some fish guidance tests by Reclamation's Fisheries and Wildlife Research Group at the TSC in Denver, Colorado. Each light unit was 20-1/4 inch (51.4 cm) in overall length, 1-1/2-inch (3.8 cm) in diameter with brass end caps about 1-15/16 (4.92 cm) inch in diameter and 2 inch (5.08 cm) long, each having 360 fps. The lights have a 3-prong connector that extended out from the end of the tube about 1-5/8 inch (4.13 cm). The effective light unit was about 16-1/4 inch (41.3 cm) long.   Two light units were mounted side by side and suspended just below the water surface at about a 45° angle to the flow upstream of the right channel (Figure 9). Five tests with 10 ammocoetes each were conducted with high flow during the daytime. Five additional tests were conducted at night.

Figure 7. Air bubble curtain in front of the right channel of the test flume.

Figure 8. Air bubble curtain repositioned 12 inches upstream.

Low voltage high intensity light bar array combined with the air bubble curtain—These two potential behavioral guidance devices were combined to assess whether when combined they might provide better guidance than either device itself. These tests were conducted at night under the high flow conditions. Since the bubble curtain had been relocated 12 inches upstream in the flume, we suspended the light array upstream over the bubble curtain and conducted five tests with the guidance devices in this configuration positioned in front of the right channel (Figure 10).

Figure 9. Low voltage high intensity light array positioned in front of the right channel in the test flume.

Figure 10. Low voltage high intensity light bar array and air bubble curtain in use in the test flume at night.

Results

Water velocity in the test flume—With the three 3-inch-diameter pumps operating at maximum capacity, and with a water depth of about 12.75 inches in the flume, average water velocity 2-inches below the surface at transect A 1.75 ft below the third diffuser plate was 0.853 fps, while at 2-inches above the bottom flow averaged 0.75 fps. At transect B, 6.5 ft from the diffuser plate, flow averaged 0.79 fps at surface and 0.70 fps at the bottom. Surface flow in the right channel at the splitter wall was 0.80 fps and 0.83 fps in the left channel, while flow at the bottom was 0.78 fps on the right and 0.72 fps on the left. At the top of the ramp with the transition to the fish slide into the fish trap the flow in the right channel was 2.08 fps and 2.14 fps in the left channel.

At the low flow with only the center pump operating, water velocity 2-inches below the surface at transect A 1.75 ft below the third diffuser plate averaged 0.61 fps, while at 2-inches above the bottom flow averaged 0.49 fps. At transect B, 6.5 ft from the diffuser plate, flow averaged 0.64 fps at surface and 0.59 fps at the bottom. Surface flow in the right channel at the splitter wall was 0.63 fps and 0.66 fps in the left channel, while flow at the bottom was 0.58 fps on the right and 0.59 fps on the left. At the top of the ramp with the transition to the fish slide into the fish trap the flow was 1.80 fps on the right side and 1.86 fps on the left side.

Distribution of Pacific lamprey ammocoetes with no guidance device in place—Ten Pacific lamprey ammocoetes each were released through the right, center and left fish introduction tubes. Of the 10 released through the right tube, four were recovered in the right channel fish trap and six in the left channel fish trap. Of the 10 ammocoetes released through the center tube, five each were recovered in the right and left channel fish traps, and of the 10 ammocoetes released through the left tube, two were recovered in the right channel fish trap and eight were recovered in the left channel fish trap.

Wedge wire screen—Wedge wire screen of the dimensions noted above appeared to guide Pacific lamprey ammocoetes and macropthalmia, as indicated by the number of Pacific lamprey recovered in the opposite channel fish trap (Table 1). All Pacific lamprey ammocoetes that were accounted for were recovered in the opposite channel fish trap. In seven of 10 tests, we recovered all 10 of the fish introduced upstream of the screen in the opposite channel fish trap. On three occasions one or two fish were not recovered in the fish trap; two were unaccounted for and in one test two fish were observed in the channel opposite the screen but they did not go over the ramp into the fish trap. They were the smallest of the 10 ammocoetes introduced and were recovered when the flow in the flume was shut off. Average length for those fish recovered in the left channel fish trap when the screen was located in front of the right channel was 121.5 mm, ranging from 108.6 mm to 127.7 mm. For fish recovered in the right channel fish trap when the screen was located in front of the left channel, fish length averaged 117.2 mm, ranging from 78 mm to 141 mm.

For the two tests conducted with Pacific lamprey macropthalmia with the wedge wire screen positioned in front of the left channel, all fish were recovered in the right channel fish trap. Average length of the 20 fish recovered was126.4 mm, ranging from 113 mm to 140 mm.

Woven wire screen—Ten tests were conducted using 4.5-12 woven wire screen, five tests run with the woven wire screen positioned in front of the left channel and five with the screen positioned in front of the right channel. With the screen in front of the left channel, most Pacific

Table 1. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of wedge-wire screen at high flow on 21 September 2010.						
Screen location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right side	1	10 ammocoetes		10		
	2	10		10		
	3	10		10		
	4	10		10		
	5	10		10		
Left side	6	10	10			
	7	10	10			
	8	10	10			
	9	10	10			
	10	10	10			
	11	10 macrop-thalmia	10			
	12	10 macro	10			

lamprey ammocoetes were recovered in the right channel fish trap, and with the screen in front of the right channel, most juveniles were recovered in the left channel fish trap.

In the first test, nine juveniles were recovered in the right channel fish trap and one in the left channel fish trap (Table 2). In the second test of the series, nine fish were recovered in the right channel fish trap and one juvenile moved up through the diffuser plate into the head box where it was recovered, and in test 3, eight ammocoetes were recovered in the right channel fish trap with an additional juvenile found in the slot in the floor of the flume. One fish was unaccounted for. We determined that the woven wire screen was not completely seated in the slot, and it was reseated about an additional 1/4 inch and resealed. In test 4 and 5, all Pacific lamprey ammocoetes released through the left side fish introduction tube were recovered in the right channel fish trap, and in test 5, an additional ammocoete was recovered, possibly one of the unaccounted for fish from test 3 that might have gone through the diffuser plate into the head box where it was not observed. All Pacific lamprey ammocoetes released were accounted for in these two tests. For the 46 fish recovered in the right channel fish trap when the woven wire screen was positioned in front of the left channel, fish length averaged 118.7 mm, ranging from 62 mm to 140 mm.

Tests 6 through 10 were conducted with the woven wire screen in front of the right channel, with Pacific lamprey ammocoetes released through the right side fish introduction tube. Fish were

Table 2. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of woven-wire screen at high flow on 22 September 2010.						
Screen location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Left	1	10 ammocoetes	9	1		
	2	10	9		1 H	
	3	10	8			2
	4	10	10			
	5	10	10			
Right	6	10		9	1 H	
	7	10		9		1
	8	10		10		
	9	10		9		1
	10	10		10		
Note: The "H" under salvaged in tests 2 and 6 indicate that one ammocoetes each was recovered upstream in the head box.						

recovered in the left channel fish trap. One fish in test 6 worked its way up through the head box diffuser plate and was recovered there, and one fish each in tests 7 and 9 were unaccounted for. For fish 47 recovered in the left channel fish trap when the screen was located in front of the right channel, fish length averaged 118.0 mm, ranging from 66 mm to 147 mm.

Air bubble curtain—The air bubble curtain did not appear to guide Pacific lamprey ammocoetes away from the channel with the bubble curtain (Table 3). In the two initial tests with ammocoetes, one at high flow and the second at low flow, six ammocoetes each were recovered after each test in the right channel fish trap downstream from the channel with the air bubble curtain, with four and two recovered in the left channel fish trap in tests 1 and 2, respectively. Two ammocoetes were recovered in the flume after flow was shut off in test 2. At the lower flow, it took somewhat longer for the fish to move downstream and some fish appeared to hold in lower velocity areas in the corners of the flume. We therefore resumed testing with higher flows. Average length of the 12 fish recovered in the right channel fish trap when the bubble curtain was positioned in front of the right channel was 110.8 mm, ranging from 74 to 137 mm, while the average length for the 6 fish recovered in the left trap was 110.7 mm, ranging from 52 to 135 mm.

In three tests with 10 Pacific lamprey macropthalmia each, with the air bubble curtain positioned upstream of the right channel, at the high flow, seven fish were recovered in the left channel fish trap while three were recovered in the right channel fish trap downstream from the bubble

Table 3. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of air bubble curtain at high flow on 22 September 2010.						
Bubble curtain location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right-High	1	10 ammocoetes	6	4		
Low	2	10	6	2	2	
High	3	10 macrop-thalmia	3	7		
	4	10	3	7		
	5	10	9	1		

curtain in the first two tests. It appeared that the air bubble curtain might be somewhat effective in guiding macropthalmia. However, in the third test, nine Pacific lamprey macropthalmia were recovered in the right channel fish trap downstream from the air bubble curtain, and only one was recovered in the left channel fish trap (Table 3). At that point we exhausted the supply of macropthalmia. Average length of the 15 fish recovered in the right channel fish trap was 128.5 mm, ranging from 122 to 137 mm, while the average length for the 15 fish recovered in the left channel fish trap was 129.7 mm, ranging from 117 to 140 mm.

Air bubble curtain repositioned upstream in the flume—In the first test with the air bubble curtain repositioned 6 inches upstream in front of the right channel, five Pacific lamprey ammocoetes were recovered in the right channel fish trap, three recovered in the left channel fish trap, and one recovered in the flume after the test (Table 4). One ammocoete moved up into the head box through the porous diffuser plate. In the second test, results were similar, but two ammocoetes were unaccounted for. Average length of the 10 fish recovered in the right channel fish trap was 118.7 mm, ranging from 88 to 139 mm, while the average length for the six fish recovered in the left channel fish trap was 113.5 mm, ranging from 79 to 134 mm.

When the bubble generator was repositioned another six inches upstream on the right side for a total of 12 inches from the entrance to the right side channel, two-thirds of the ammocoetes (20 of 30) were recovered in the right channel fish trap downstream from the bubble curtain, while 26.7 percent (8 of 30) were recovered in the left channel fish trap. One ammocoete moved up into the head box and one was unaccounted for. Average length of the 20 fish recovered in the right channel fish trap was 129.6 mm, ranging from 90 to 141 mm, while the average length for the eight fish recovered in the left channel fish trap was 126.1 mm, ranging from 100 to 140 mm.

In tests 6 through 10, with the air bubble curtain 12 inches upstream from the right channel mouth, with reduced flow, 26 ammocoetes were recovered in the left channel fish trap, while 20

Table 4. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of bubble curtain at high and low flows on 23 September 2010, with the bubble curtain repositioned 6 and 12 inches upstream from the mouth of the channel.						
Bubble curtain location	Test No.	No. released	Number recovered			
Right			Right trap	Left trap	Salvaged	Missing
6 inches upstream	1	10 ammocoetes	5	3	2	
	2	10	5	3		2
12 inches upstream	3	10	5	4	1	
	4	10	7	2		1
	5	10	8	2		
Low flow	6	10	5	4		1
	7	10	5	4	1	
	8	10	2	8		
	9	10	4	6		
	10	10	4	4	2	

ammocoetes were recovered in the right channel fish trap downstream from the bubble curtain. Three ammocoetes were recovered in the flume after the tests were terminated and the flow was shut down, and one ammocoete was unaccounted for.

Average length of the 20 fish recovered in the right channel fish trap for these five tests was 119.3 mm, ranging from 78 to 142 mm, while the average length for the 26 fish recovered in the left channel fish trap was 109.4 mm, ranging from 77 to 131 mm.

Low voltage high intensity light bar array—In five daytime tests with the low voltage high intensity light units, 27 Pacific lamprey ammocoetes were recovered in the right channel fish trap below the light array, 20 were recovered in the left channel fish trap, one was recovered after the flow was shut off, and two were unaccounted for (Table 5). Average length of the 27 fish recovered in the right channel fish trap was 121.9 mm, ranging from 84 to 139 mm, while the average length for the 20 fish recovered in the left channel fish trap was 123.3 mm, ranging from 112 to 132 mm.

During five additional nighttime tests, the results were nearly reversed, with 20 ammocoetes recovered in the right channel fish trap downstream from the light array, 28 recovered in the left channel fish trap, and two recovered after flow was shut down (Table 6). Average length of the 20 fish recovered in the right channel fish trap was 118.1 mm, ranging from 69 to 140 mm, while

Table 5. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights at high flow during the daytime on 23 September 2010.

Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	5	4	1	
	2	10	6	4		
	3	10	6	4		
	4	10	7	3		
	5	10	3	5		2

Table 6. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights at high flow during the nighttime on 23 September 2010.

Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	4	5	1	
	2	10	5	4	1	
	3	10	4	6		
	4	10	3	7		
	5	10	4	6		

the average length of the 28 fish recovered in the left channel fish trap was 124.1 mm, ranging from 106 to 151 mm.

Low voltage high intensity light bar array combined with air bubble curtain—In a series of five nighttime tests that combined both the low voltage high intensity light array and the air bubble curtain in front of the right channel, 23 ammocoetes were recovered in the right channel fish trap downstream from the light bar array-bubble curtain, while 25 were recovered in the left channel fish trap, and two recovered after flow in the flume was shut down (Table 7). Average length of the 23 fish recovered in the right channel fish trap was 121.1 mm, ranging from 87 to 141 mm, while the average length for the 25 fish recovered in the left channel fish trap was 121.1 mm, ranging from 84 to 140 mm.

Table 7. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights and the bubble curtain at high flow during the nighttime on 23 September 2010.						
Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	7	3		
	2	10	4	6		
	3	10	5	4	1	
	4	10	5	5		
	5	10	2	7	1	

Discussion

Wedge wire screen—Wedge wire screen meeting NOAA Fisheries criteria for fry successfully guided Pacific lamprey ammocoetes. In the 10 tests, all ammocoetes were recovered in the opposite channel fish trap. In two tests with 10 Pacific lamprey macropthalmia each, they also were recovered in the opposite channel fish trap. Four ammocoetes were unaccounted for; juvenile Pacific lamprey appear to be particularly adept at finding small gaps in the flume to either escape the fish traps and return back to the river in the outflow, or simply hiding in small gaps and crevasses. These tests indicate that Pacific lamprey ammocoetes can be guided successfully with wedge wire screen meeting NOAA Fisheries criteria for fry, oriented vertically at a 30 degree angle to the flow. If wedge wire screen were to be selected for installation at water diversions to reduce or eliminate juvenile Pacific lamprey entrainment, the actual location and size and operation of the screen would have to be considered carefully to avoid the screen becoming plugged with debris.

Woven wire screen—Most (93 of 100) of the Pacific lamprey ammocoetes were guided by the woven wire screen at the high flow of about 0.85 fps. In the initial tests, the fish recovered from the left channel fish trap when the screen was positioned in front of the left channel may have passed through a small gap at the bottom of the screen that resulted from the screen inadvertently not being completely seated in the slot. After the screen was reseated and the gap sealed, all juveniles were recovered in the opposite channel fish trap, indicating that this screen type successfully guided the fish. Two juvenile Pacific lamprey worked their way up through the ¼-inch openings of the porous diffuser perforated plate and entered the head box, where they were recovered. Two ammocoetes were not recovered and their fate is unknown. Pacific lamprey ammocoetes appear to be quite adept at getting through small gaps and crevasses and either escape back to the river in the outflow or simply hide along the edge of screens or any protrusion in the channel.

Air bubble curtain—The air bubble curtain when positioned in front of the right channel did not appear to guide Pacific lamprey ammocoetes effectively to the opposite channel, as evidenced by the number of fish recovered in the fish trap below the bubble curtain; more (12 of 20 or 60 percent) were captured in the fish trap downstream from the bubble curtain, while 8 of 20 (40 percent) were recovered in the opposite channel fish trap. In three tests with 10 Pacific lamprey macropthalmia each, 15 macropthalmia each were recovered in each fish trap. In the first two of these three tests, it appeared that the macropthalmia were responding to the bubble curtain, with 7 out of 10 fish recovered in the left channel fish trap, but in the third and last test of the series, only one fish was recovered in the left channel fish trap while the other nine fish were recovered in the right channel fish trap downstream from the bubble curtain. Based on the tests conducted here, it does not appear that the bubble curtain is a reliable and effective method to guide Pacific lamprey ammocoetes.

When the bubble curtain was repositioned 6 inches upstream from the mouth of the channel, half of the released ammocoetes were recovered in the right channel fish trap, and 40 percent were recovered in the left channel fish trap, indicating that the bubble curtain did not appear to be a very effective guidance device. When we moved the bubble curtain upstream another 6 inches, about two thirds of the fish were recovered in the right channel fish trap and about 27 percent were recovered in the left channel fish trap. These tests were conducted at the high flow. After we reduced the flow, with the bubble curtain 12 inches upstream from the mouth of the channel, there was slightly better recovery of test fish in the fish trap opposite the bubble curtain and site of release; 52 percent were recovered there and 40 percent were recovered in the right channel fish trap. Six percent of the fish were recovered in the flume after the tests were terminated and one fish was unaccounted for. It appears that with the reduced flow and the bubble curtain positioned upstream from the mouth of the channel there was slightly better guidance of the fish away from the channel. It is possible that Pacific lamprey might respond differently to finer or coarser bubbles. Further testing using different types of porous tubing that produced a finer bubble stream might elicit a different response from the lamprey ammocoetes. Finer bubbles than those generated in these tests might produce a tighter bubble curtain, perhaps affecting guidance. Lower water velocity reduced the drag on the bubbles into the channel, but the ammocoetes moved downstream more slowly in the reduced flow. Although Pacific lamprey ammocoetes are generally sedentary, they are relatively good swimmers for their size. Sutphin (2010) reported that Pacific lamprey ammocoetes from 107 to 150 mm TL had a burst swimming speed ranging from 33.3 to 75 cm/sec (1.09 to 2.46 fps), which may explain why they moved downstream in the flume slower under the low flow condition because they were not overwhelmed by the low flow of 0.61 fps. We observed ammocoetes swimming actively both upstream and downstream in the flume. In a field application of an air bubble curtain, where the diversion generally takes off from the river at an angle, a bubble curtain might be more effective than when the bubble curtain is positioned directly in front of a channel in line with the flow, as it was in the test flume.

Low voltage high intensity light bar array—During daytime tests with the high flow, 54 percent of the ammocoetes were recovered in the right channel fish trap downstream from the low voltage high intensity light bar array, with 40 percent recovered from the left channel fish trap. However, during the five nighttime tests, 56 percent of the ammocoetes were recovered in the left channel fish trap, while 40 percent were recovered in the right channel fish trap. Pacific lamprey juveniles are generally more active at night, and the propensity for greater nighttime movement might affect their response to the high intensity lights. Since Pacific lamprey ammocoetes do not have developed eyes, it is not known why or whether they would respond to light. During the daytime, the high intensity light bar array might not be much different from the full sunlight condition that prevailed during the tests. The light bar array might have been more effective if it had been recessed in the floor of the flume rather than suspended just below the water surface. The light tube was too large to set flush in the floor of the flume as it is currently configured; the light tube itself might have served as a physical guidance device for any Pacific lamprey ammocoetes moving along the bottom of the flume. Little is known about how Pacific lamprey ammocoetes respond to various environmental cues. Additional research is needed to elucidate the response of juvenile lamprey to environmental stimuli since they do not have developed eyes at this life stage. Macropthalmia with developed eys might respond differently to the high intensity light array.

Low voltage high intensity light bar array combined with the air bubble curtain—The combined low voltage high intensity light bar array and the air bubble curtain tested during the nighttime resulted in about equal numbers of Pacific lamprey ammocoetes being guided as not. With two fish recovered in the flume after the tests were terminated, 25 ammocoetes (50 percent) were recovered in the left channel fish trap, with 23 (46 percent) recovered in the right channel fish trap. Under the conditions of these tests, it does not appear that the combination of the light array and the bubble curtain provides any better guidance of Pacific lamprey ammocoetes than the light bar array itself, during nighttime. It would be informative to modify this flume or construct a new flume in which the high intensity light bar and/or air bubble curtain could be recessed and flush with the floor of the flume and conduct several additional tests.

Some additional observations on behavior of Pacific lamprey ammocoetes—Pacific lamprey ammocoetes exhibited some interesting behavior both in the holding tanks and in the test flume. They appeared to be very sensitive to disturbance in the holding tank, such as when they were dislodged out of the substrate and netted for testing in the flume. The holding tanks for the ammocoetes had a substrate of Quickrete Play Sand about 3 inches deep to allow them to burrow. This material was recommended by staff at the Columbia River Research Laboratory, Cook Washington, as a suitable substrate for rearing Pacific lamprey ammocoetes. After the substrate was disturbed and fish collected to introduce into the flume, they relatively quickly burrowed back into the substrate. They generally burrowed head first, often at a shallow angle rather than vertical. Many remained completely buried in the substrate.

Summary

Physical guidance devices such as wedge wire and woven wire screens appear to guide Pacific lamprey ammocoetes and macropthalmia away from a channel, while the air bubble curtain and the low voltage high intensity light bar array as tested here did not provide consistent guidance, at least under the conditions of the field tests.

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APPENDIX F

Swimming Performance of Larval Pacific Lamprey
(Lampetra tridentata)

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Swimming Performance of Larval Pacific Lamprey (*Lampetra tridentata*)

Abstract

Laboratory experiments were conducted to measure the prolonged-sustained and burst swimming speeds of wild larval (ammocoete) Pacific lamprey (*Lampetra tridentate*). Prolonged-sustained speeds were measured using an annular variable speed swimming chamber and burst speeds were determined using a swimming raceway and digital video analysis. During prolonged-sustained swimming experiments, the mean length of time lamprey (72 – 143 mm TL) were able to swim in the chamber ranged from 43.0 min when exposed to a velocity of 10 cm/s, to 0.4 min when exposed to 50 cm/s. The burst swimming speeds of lamprey tended to increase as length increased from 107 to 150 mm TL, and ranged from 33.3 to 75.0 cm/s. Our estimates of the overall swimming performance of this life-stage are the first reported for this species, and can provide important information when developing approach velocities and infrastructure to improve lamprey passage while minimizing entrainment loss.

Introduction

Pacific lamprey (*Lampretra tridentata*) have declined in abundance throughout much of their native range, including the Columbia River Basin, over the last half century (Close et al. 1995, 2002; Close 2001). A multitude of anthropogenic factors (see Close et al. 1995) have contributed to the decline and subsequent protected status by the state of Oregon (Kostow 2002) and recent petitioning for protected status under the ESA (Dauble et al. 2006). Of particular concern to larval (ammocoetes) and juvenile (macropthalmia) life-stages of the lamprey are the direct and indirect effects of water diversions, barrier screens, and fish pathways that are abundant throughout much of their native habitat and are typically not designed considering the species physical (i.e. swimming ability) requirements (Dauble et al. 2006).

Pacific lamprey are of significant ecological importance in the Columbia River Basin. They play a key role in benthos nutrient cycling (Kan 1975), are an important food source for native piscivores (Close et al. 2002), and are of significant cultural importance for native peoples of the Pacific Northwest (Close et al. 2002). Though generally spending much of their larval life (4 – 6 years) burrowed in the soft sediments (Kan 1975, Richards 1980), scouring events (Close et al. 2002) and significant water discharges (Pirtle et al. 2003) may cause ammocoetes to be dislodged from the sediments and enter the water column. Without suitable refuge ammocoetes risk exposure to water velocities they are physically unable to traverse, increasing the likelihood of damage and mortality as a result of exposure to hydropower turbines, water diversions, and barrier screens (Moursund et al. 2003, Dauble et al. 2006).

Based on a thorough literature review, data on the swimming performance of ammocoete Pacific lamprey has yet to be published. Therefore, there is a lack of basic knowledge pertaining to the sustained, prolonged and burst swimming capabilities of the species which can provide important information for their management. For example, the entire range of swimming speeds that can be achieved by a species, the sustained and prolonged speeds in particular, provide important information that can be used in the development of improved physical and non-physical barrier designs, diversion structures, and the establishment of suitable water velocities at such structures (Conrad et al. 1999, Wolter and Arlinghaus 2003, Tudorache et al. 2008). Also, burst speeds attained by fish are ecologically significant because these speeds are most commonly employed as a means to evade predation (Beamish 1978). Therefore, the objec-

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tive of this study was to measure the swimming performance of larval Pacific lamprey over the entire range of swimming speeds (sustained, prolonged and burst speeds) they may be forced to utilize in their natural environment.

Methods

Ammocoete Pacific lamprey were collected by electrofishing on July 24, 2009 from the Umatilla River (rivermile 67.5) by Umatilla Tribe employees, were transferred via aerated coolers to holding tanks and slowly (over one day) tempered from 23 to 20 °C. A subset of these fish (~ 300 individuals), identified by tribal biologists as 1-4 year olds (A. Jackson 2009, personal communication), were transported to the Bureau of Reclamation's (BOR) Mobile Fisheries Research Laboratory (MFRL) for holding and testing on July 28, 2009. The MFRL, a transportable and self-contained fish testing laboratory, was positioned adjacent to McKay Creek, a tributary of the Umatilla River, just upstream of the McKay Creek adult fish barrier in Pendleton, Oregon. During swim performance testing ammocoetes were maintained in 87-L circular polyethylene holding tanks and provided continuous flows, at approximately 0.5 L/min of treated (ultraviolet sterilization and particle filtered), temperature controlled (in-line chiller; Aqualogic, Inc., San Diego, CA) water maintained at 20.8 ± 1.3°C (mean ± SD). Fish were held and tested at a water temperature near the temperature recorded during capture to minimize the time required for thermal acclimation. Water quality was checked at least twice daily using a YSI85 multifunction meter (YSI, Inc., Yellow Springs, OH.) and an ammonia test kit (LaMotte Company, Chestertown, MD.). Mean (± SD) dissolved oxygen and total ammonia nitrogen levels were 8.8 ± 0.6 mg/L and 0.2 ± 0.1 mg/L, respectively. Ammocoetes were provided a narrow range (1- 4 cm/s) of velocities during holding, but were not provided substrate or cover. Pacific lamprey were not fed during testing.

Burst Swimming Tests

A burst swimming raceway (220-cm length and 30-cm wide), filled to 25 cm depth and provided with a black 1 x 1-cm grid on the bottom to provide scale, was used to measure the burst swimming speed of ammocoete Pacific lamprey. Water in the raceway was quiescent during testing and there was no water exchange. However, due to the short duration of each replicate (< 5 min) there was no measurable change in water temperature during testing and dissolved oxygen levels remained > 8 mg/L. For each replicate, a single ammocoete was netted from its holding tank, transferred to a 19-L bucket containing ~ 8 L of water, placed in the raceway, and allowed to adjust to the new environment for one minute. The ammocoete was then induced to swim by touching their caudal region with a plastic rod. Induction of swimming via plastic rod was conducted by the same individual to minimize differences in force applied to the test specimen. Repeated touching of the caudal region continued for an approximate one minute period or until researchers observed the ammocoete making a significant effort to avoid contact from the plastic rod (e.g., burst swimming). Burst swimming of lamprey was recorded at 60 frames per second using an overhead video camera (Hitachi, Ltd.; Chiyoda-ku, Tokyo). The maximum burst speed for an individual lamprey was considered the fastest speed achieved over a 10-cm distance during the one minute test period.

Prolonged-Sustained Swimming Tests

Two circular swimming flumes were used to measure the prolonged-sustained swimming abilities of ammocoete Pacific lamprey. Both flumes were equipped with a fish swimming chamber, interchangeable honeycomb filters, adjustable vanes and cross-wings for producing laminar flow through the swimming chamber, and were precalibrated using a Marsh McBirney flow meter (Hach Company, Loveland, Colorado). Water was circulated through each chamber using a variable speed 120V/60Hz motor (SEW-Eurodrive, Hayward, CA.) controlled by a digital motor control center. Prolonged swimming of fish was generally defined as the water velocity a fish can maintain for periods between 20 seconds 200 min, whereas sustained swimming can be maintained for periods > 200 min (Beamish 1978). However, even at our lowest test velocities (10 cm/s) lamprey either (1) chose not to swim for periods > 60 minutes or (2) were able to anchor themselves on the bottom of the flume. Thus, for this research we combined prolonged and sustained fish swimming categories. Preliminary observations suggested larval lamprey were occasionally unwilling to swim in a flume and against current, and early life-stages of Pacific lamprey tend to be most active at night (Dauble et al. 2006). All tests were completed with the laboratory lights off, the upstream end of the swimming flume covered with black sheets of plastic, and the downstream end exposed to a high intensity light to deter ammocoetes from entering this region. This configuration generally resulted in lamprey being more willing to swim against the current to stay away from the light. Due to the short duration of each replicate the water temperature was minimally affected by the use of lights during testing, and the range of increasing temperatures during testing was between 0.0 and 0.3°C. For each replicate, a single ammocoete was netted from its holding tank, transferred to a 19-L bucket containing ~ 8 L of water, placed in the raceway, provided 15 minutes of exposure to 0 cm/s velocity, then 5 minutes with a velocity of 5 cm/s to allow ammocoetes the opportunity to sense and orient into the current. The water velocity was then increased to a randomly selected velocity, between 10 and 50 cm/s in 5 cm/s intervals, at which point the ammocoetes swam until fatigued or until 60 min was reached. Fatigue was defined as complete impingement of the fish on the downstream end of the test chamber. Once fatigue (or 60 min) was reached, water velocity in the flume was returned to 0 cm/s, time (min and sec) the individual was able to swim at the given velocity was recorded. After each replicate, for both burst and sustained-prolonged swimming tests, lamprey were removed from the test flume, measured for wet weight (WW) to the nearest 0.1 g and for length (standard, fork, and total length) to the nearest 1 mm.

Statistical Analysis

One-way analyses of variance (ANOVA) was used to compare fish morphometrics among treatments. Exponential models were fitted to data from prolonged-sustained swimming data. All statistical analyses were conducted using SAS 9.1 (SAS 2005), and the alpha level for all analyses was set at 0.05. During both burst swimming and prolonged-sustained swimming trials fish that did not choose to swim at full capacity, based on our judgment, were considered to have not participated in the experiments and were therefore not included in the data analysis.

Results

During holding and prior to testing lamprey were generally quiescent, remaining still on the tank bottom, but occasionally swimming for short durations before returning to the tank bottom. Burst swimming speeds of ammocoete Pacific lamprey ranged from 31.6 to 75.0 cm/s (2.55 – 5.56 body lengths per second [BL/s]), with a mean (± SD) of 51.6 ± 13.0 cm/s (3.74 BL/s, n = 19). In general, ammocoetes displayed burst swimming (i.e., avoidance behavior) after initial contact from the plastic rod, but would only burst swim for short (< 40 cm) distances. Also, the burst swimming speed of lamprey tended to increase with increasing size (Figure 1). Of the 25 fish tested, a total of six lamprey did not perform in the burst swimming experiments. Mean total length and weight of lamprey used during burst swimming tests were 112.1 ± 28.3 mm and 3.4 ± 1.7 g, respectively. Mean (± SD) water temperature during burst swimming experiments was 21.1 ± 0.3°C.

During prolonged-sustained swimming replicates the length of time sustained in the swimming chamber tended to decrease from a mean (± SD) of 43.04 ± 19.65 min when exposed to a velocity of 10 cm/s (n = 4) to 0.55 ± 0.07 min and 0.35 min when exposed to velocities of 45 (n = 4) and 50 cm/s (n = 1), respectively (Figure 2). One fish each at velocities of 25, 30, 35, and 40 cm/s, and two fish each at velocities of 15 and 45 cm/s did not participate in the prolonged-sustained swimming experiments. Lamprey used in sustained-prolonged

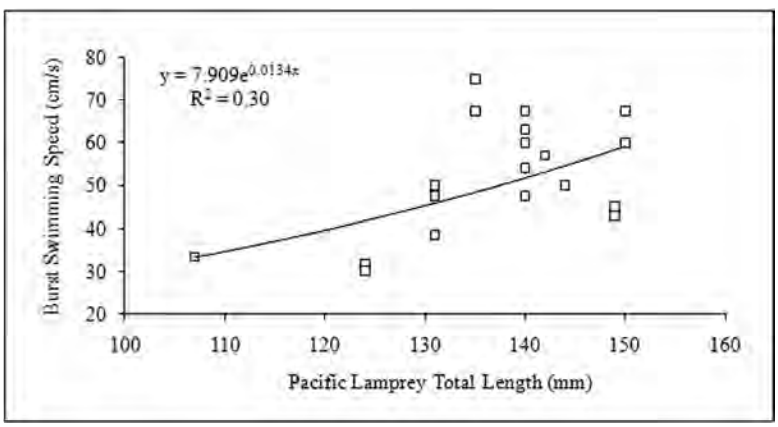

Figure 1. Burst swimming speeds (cm/s) of Pacific lamprey.

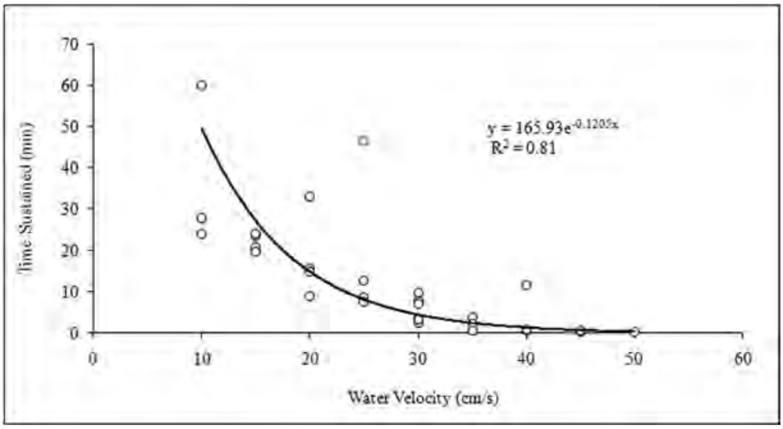

Figure 2. Minutes that individual ammocoete lamprey were able to sustain position in the swimming chamber at water velocities (cm/s) between 10 and 50 cm/s before becoming impinged. Trials lasted for a maximum of 60 minutes.

swimming trials were of similar total length (120.2 ± 25 mm; ANOVA: P > 0.05) and wet weight (3.27 ± 0.97 g; ANOVA: P > 0.05). Mean (± SD) water temperature during prolonged-sustained swimming experiments was 20.9 ± 1.0°C.

Discussion

Based on our literature review this is the first available data on the swimming performance of larval Pacific lamprey. Interestingly, sustained swimming speed, and to a lesser extent the burst swimming speed, of juvenile Pacific lamprey as reported by Dauble et al. (2006) are similar to our measured values. Dauble et al. (2006) reported slightly higher mean (± SD) burst speed of juvenile lamprey (71 ± 5 cm/s) and indicated swimming endurance decreased as velocities increased from 15 to 30 cm/s, but decreased rapidly with increases in velocity > 46 cm/s. These similarities in swimming performance are likely because the size of our test fish, for both burst and prolonged-sustained swimming experiments, were similar to the length of juvenile lamprey (136 ± 5 mm) used by Dauble et al. (2006). It would therefore be beneficial to include smaller size classes of ammocoetes in any future research aimed at measuring swimming performance of Pacific lamprey. This is particularly relevant because events that cause larval lamprey to be dislodged from their burrows typically results in dislodging of multiple age-classes.

In comparison to other resident fish of similar size in the Columbia River basin, larval Pacific lamprey are poor swimmers. For example, Bainbridge (1958) reported juvenile (40 -130 mm TL) rainbow trout (*Oncorhynchus mykiss*) can achieve burst speeds up to 18 BL/s and 220 cm/s, and in a later document Bainbridge (1960) reported 103 – 150 mm TL trout can achieve burst speeds between 105 and 175 cm/s. Also, Hale (1996) reported late-larval stage (30 – 35 mm TL) Chinook salmon (*O. tshawytscha*) achieve burst speeds > 80 cm/s. Brett et al. (1958) reported 6.9 cm sockeye salmon (*O. nerka*) can sustain swimming speeds of 35 cm/s for one hour. This likely poses a problem for poor swimming larval and juvenile Pacific lamprey in the Columbia River Basin because much of the water velocity criteria used to develop water diversion and intake velocities consider the swimming ability of native salmonids. For example, water velocity at screening structures near water withdrawal pumps exclude juvenile salmon by requiring maximum approach velocities of 15.3 cm/s, whereas fishways adjacent to dams promote salmon passage by maintaining entrance velocities near 305 cm/s (Ostrand 2004; Johnson et al. 2008). It is therefore no surprise that lamprey often incur elevated impingement rates at man-made structures and are often unsuccessful at bypassing dams in the Columbia River Basin (Moursund et al. 2003).

In conclusion, our results provide basic data on the swimming abilities of larval Pacific lamprey that could potentially be used by water diversion designers concerned with lamprey passage or entrainment. Our results also suggest larval Pacific lamprey are generally poor swimmers and if dislodged from the sediments they may have difficulty negotiating and avoiding water diversions and barriers. However, it would be appropriate to conduct similar research on a wider size range of ammocoetes over the broader range of temperatures they encounter in the Columbia River

Basin. Also, future research requiring holding of lamprey should aim to minimize possible stress and energetic output of lamprey by providing an environment (i.e., soft substrate for burrowing) more representative of natural conditions.

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