AFEP 2017 RESEARCH PROPOSAL
SUBMITTED TO THE
U.S. ARMY CORPS OF ENGINEERS
Northwestern Division

I. Basic Information

A. Title

Develop Research, Monitoring, and Evaluation Plan to Guide Future Juvenile Lamprey Passage Investigations

B. Project Leaders

Z. Daniel Deng, Ph.D.
Pacific Northwest National Laboratory
Richland, WA 99352
Tel: 509/372-6120
Email: zhiqun.deng@pnl.gov

Bob Mueller
Pacific Northwest National Laboratory
Richland, WA 99352
Tel: 509/371-7229
Email: robert.mueller@pnnl.gov

Alison Colotelo
Pacific Northwest National Laboratory
Richland, WA 99352
Tel: 509/371-7248
Email: Alison.Colotelo@pnnl.gov

C. Study Code

LMP-S-16-1

D. Corps Technical Point of Contact

Ricardo Walker and Steve Juhnke

E. Anticipated Duration

October 9, 2016 to March 31, 2018

F. Date of Submission

September 29, 2016

II. Project Summary

A. Project Goal(s)

The goal of this project is to develop a Research, Monitoring, and Evaluation (RME) Plan to inform planning and prioritization for future juvenile lamprey passage investigations. The RME Plan developed under this project will identify information gaps, facilitate discussions among regional managers, ensure that limited resources are applied effectively to inform specific management decisions, and facilitate coordination of USACE efforts with regional lamprey conservation actions.

B. Objectives(s)

1) In coordination with the technical POC and regional managers, identify information gaps and specific management questions relative to understanding and addressing juvenile Pacific lamprey (ammocoete, macropthalmia, and transitional phases) near FCRPS dams.
2) Based on results from Objective 1, determine the most appropriate and feasible methods for addressing primary management questions. Considerations may include: (a) sample size requirements to achieve objectives; (b) methods for capture, tagging, and recapture of juvenile lamprey; (c) relative cost, and; (d) opportunities to create efficiencies by collaborating with ongoing monitoring projects.
3) Based on results from Objective 1, juvenile lamprey acoustic transmitter development efforts in 2015-2017, and in coordination with the technical POC and regional managers, develop a pilot level study in 2017 and a full scale study, to be completed at a later date as funding and resources allow.
    - Pilot level study may include: collection locations, tagging and release locations, horizontal and vertical distribution near the dam (reservoir and forebay), and detection probabilities of the lamprey tags.
    - Full scale study may include: collections locations, tagging and release locations, behavior and passage at dams.

C. Methods

The RME plan will be developed in collaboration with regional managers and stakeholders. Controlled field testing and preliminary field performance will be conducted in the Columbia River Basin.

D. 2008 FISH ACCORD MOA REFERNECE:

Juvenile Lamprey (JL) MOAs: 1, 2, 3, 4, and 5.

III. Project Description

A. Introduction

In the Columbia River Basin, awareness and concern for understanding the entire life cycle of the Pacific lampreys (*Entosphenus tridentatus*) has escalated because populations have severely declined in the past 40 years (Close et al. 1995; Kareiva et al. 2000). Construction and operation of hydroelectric facilities may negatively impact juvenile lamprey because these declines occurred after the period of major hydroelectric development (Moursund et al. 2003; Dauble et al. 2006). One potential source of mortality is during dam passage, as juvenile Pacific lamprey out-migrate to the ocean.

Knowledge of juvenile lamprey behavior and survival are critical for developing mitigation strategies for downstream passage, including design of bypass systems at hydroelectric facilities and for irrigation diversion structures (Moser et al. 2015). Mueller at al. (2006) demonstrated the feasibility of tagging juvenile Pacific lampreys with Passive Integrated Transponders (PIT-tags). However, the detection probability of PIT-tagged fish on their downstream migration is relatively low; generally ranging from 5% to 70% of the fish passing a specific hydroelectric facility, depending on features of the juvenile bypass facilities and dam operations (Muir et al. 2001). It is probable that detection probability of PIT-tagged juvenile lamprey is significantly lower than that of juvenile salmon due to differences in migratory behavior. For example, juvenile lamprey are thought to migrate deeper in the water column than juvenile salmon and so are less likely to pass through the juvenile bypass systems (Colotelo et al. 2012). Regional lamprey workgroups have identified a need for better understanding of FCRPS impacts on all larval and juvenile lamprey life stages. Management considerations include understanding the timing and magnitude of juvenile Pacific lamprey outmigration, spatial distribution and behavior near dams, passage route use and survival at dams, and determining impacts of FCRPS operations on lamprey that may be rearing in mainstem habitats. Therefore, telemetry technology with active tag is preferred over PIT-tag technology.

The U.S. Army Corps of Engineers (USACE) has developed and is currently using the Juvenile Salmon Acoustic Telemetry System (JSATS) consisting of acoustic transmitters (tags) and autonomous, cabled, and portable receivers to evaluate the behavior and survival of juvenile salmonids migrating past dams in the FCRPS, Willamette River basin, and through the lower Columbia River estuary to ocean entry (McMichael et al. 2010, Weiland et al. 2011, Deng et al. 2011). Due to the small size of juvenile salmonids, considerable effort has been expended to understand the biological effects of implantation of JSATS transmitters in yearling and subyearling Chinook salmon. With funding from USACE, Pacific Northwest National Laboratory (PNNL) also developed a new generation transmitter that can be implanted using injection instead of surgery and was successfully evaluated in a field study (Deng et al. 2015). It weighs 216 mg, and measures 3.4 mm in diameter and 15 mm in length (Figure 1). Tag life extends more than 120 days if the tag transmits a signal every 3 seconds, more than 4 times longer than the conventional transmitter. The smaller size and improved implantation method results in a significant reduction in cost, as well as the adverse effects of biological handling of the salmon. The field trial demonstrated that the single reach survival rates of fish tagged with the injectable tag were significantly better than those of the fish tagged with commonly used transmitters.

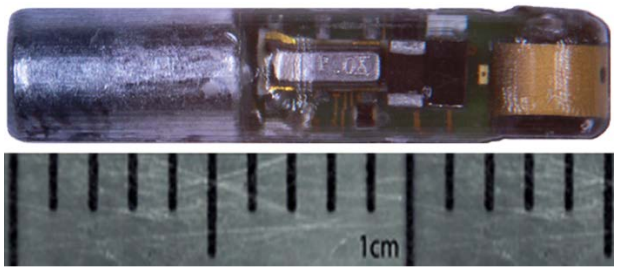

Figure 1. Injectable transmitter shown with a scale.

Despite the size reduction of the JSATS injectable tag, it is still too large to be implanted in juvenile lamprey due to their thin and flexible body. Currently, the USACE and the Department of Energy (DOE) are co-funding PNNL to design, prototype, and perform laboratory evaluation of an acoustic transmitter that can be used to study the behavior and survival of juvenile lamprey. The development is progressing as planned and is on schedule for completion in 2016 and for limited field trial in 2017. The new tag is 12 mm long and 2.0 mm in diameter, and weighs approximately 0.087 grams in air (Figure 2). It has a source level of 147 dB, which results in an 80-140-meter detection range in a realistic environment. The prototype tag lasts 20 to 30 days at 5-s ping rate interval.

In 2015, PNNL also evaluated the survival, tag retention, and swimming ability for juvenile Pacific lamprey implanted with dummy tags, which were 11.4 mm long x 2 mm in diameter and weighed 0.088 g in air. The biological tagging results show that tagging with the new tags is likely to have no adverse impacts to fish survivorship over a 28 day holding period with minimal tag loss due to shedding for fish greater than 130mm in length. The surgical operation procedure was effective at placing tags in the body cavity without causing significant hemorrhaging or fungal infections at the tagging site. The sustained swimming tests showed no significant differences in swimming ability between implanted and control fish groups for all size classes tested (120-160 mm).

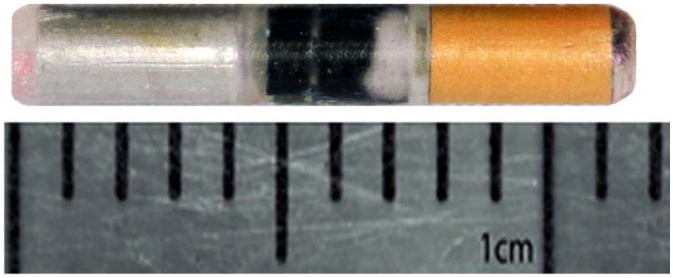

Figure 2: The newly developed juvenile lamprey eel acoustic transmitter

B. Methods

Task 1: Identify information gaps and management questions

We will start with the synthesis of previous passage work related to juvenile Pacific lamprey (ammocoete, macropthalmia, and transitional phases) conducted by Mesa et al (2015). We will arrange a series of meetings with stakeholders and work closely with the technical POC and regional managers to identify information gaps and specific management questions relative to understanding and addressing juvenile Pacific lamprey near FCRPS dams. We will focus on the following topics:

- Identify and evaluate any available data on dam/turbine impacts on downstream juvenile passage and survival of juvenile lamprey
- Document any information about lamprey survival through juvenile bypass facilities; impingement at intake diversion screens; responses of juvenile lamprey to simulated turbine passage environments (Colotelo et al. 2012).
- Identifying and determining the magnitudes of the avian predation on juvenile lamprey.
- Documenting methods used to collect data and efficiencies of the methods

Task 2: Develop RME plan

Based on results from task 1, we will assess the feasibility of various technologies for various applications. We will also develop a detailed, comprehensive plan to guide future juvenile lamprey passage and survival studies at the USACE dams on the Snake and Columbia rivers. . It will be developed collaboratively with USACE, regional agencies, and other regional stakeholders. The collaboration will be facilitated through a series of regional forums.

Task 2A Assessment of all relevant technologies

We will evaluate the feasibilities of various technologies for studying juvenile lamprey. Technologies will include PIT, radio telemetry, screw traps, and acoustic telemetry. For each recommended technology, we will include relevant research questions, study design, and associated cost.

Task 2B: Passage study plan using acoustic telemetry

This plan will be similar to other plans developed for implementing studies to estimate survival and passage metrics of juvenile salmonids using acoustic telemetry technology. As part of this project, PNNL will conduct a preliminary field trial (Task 3) to verify the performance of the newly developed juvenile lamprey tag in the field and determine future sample size requirements and detection array design for studies that evaluate the distribution of test fish and estimate survival of juvenile lamprey through dams. Additionally, PNNL will determine the feasibility of methods for the capture, tagging, and detection of juvenile lamprey at FCRPS dams that could lead to determining route-specific passage and survival estimates. Controlled laboratory experiments and limited field trials will be conducted to verify the feasibility of these methods and to derive detailed protocols. The findings and resulting protocols will be

documented in detail in the RME. PNNL will coordinate with staff from the USACE and Pacific States Marine Fisheries Commission at FCRS dams that have juvenile fish collection facilities. We will determine appropriate collection locations of juvenile lamprey based on run timing and sample rates to determine the appropriate number of fish collected to meet requirements for statistical power analysis

PNNL will develop detailed methods to better enumerate juvenile lamprey passage at FCRPS dams using JSATS, including improved methods for estimating JBS passage route and use of TSW/RSW. The new lamprey tag will have different detection range and tag life from the tags used for juvenile salmonids due to significant improvements in the performance of JSATS. In a laboratory environment, a new decoder was able to decode signals with lower signal strength than the previous decoder, significantly increasing decoding efficiency and range. In field testing, a new algorithm decoded significantly more signals than the previous decoder and three-dimensional tracking experiments showed that the new decoder's time-of-arrival estimates were accurate (Ingraham et al. 2014a). At multiple distances from hydrophones, the new algorithm tracked more points more accurately than the previous decoder (Li et al. 2014). The performance of JSATS in confined spaces was also recently confirmed (Jung et al. 2015) and is applicable for estimating the JBS passage route without using a PIT-tag. The study plan will incorporate all these differences and major improvements to the JSATS.

The plan will be developed to facilitate the determination of the effectiveness of structural and operational changes designed to improve juvenile lamprey passage and survival. PNNL demonstrated that it is possible to detect and track JSATS acoustics tags in three dimensions at all measurement locations within 100-m to the hydrophones in the Ice Harbor Dam powerhouse tailrace (Ingraham et al. 2014b). PNNL also demonstrated at Lyons Ferry on the Snake River that it is feasible to achieve detection and tracking probabilities of 99.98% and 3-D tracking with sub-meter accuracy using JSATS in a reservoir between two dams (Li et al. 2015a). The results and protocols from those field experiments will provide a better understanding of juvenile lamprey migration behavior as they pass through dams and continue downstream through the river between dams, leading to flexibility of study design and confidence of determining the effectiveness of structural and operational changes.

Finally, PNNL will facilitate the identification and evaluation of critical uncertainties relative to juvenile lamprey passage efforts by developing a detailed plan for determining the characteristics of juvenile and larval Pacific lamprey in turbine intakes and the distribution (both vertical and horizontal) of juvenile lamprey at FCRPS dams. PNNL recently completed a study at Little Goose and Lower Monumental dams to understand the behavior of JSATS-tagged juvenile salmonids, in both vertical and horizontal dimensions in the dam forebays, as they approach turbines and what the implications are for turbine passage survival (Li et al. 2015c). In addition, JSATS is well-suited for studying fish behavior in turbine intakes because JSATS uses a relatively short signal duration (744 µs) compared to other acoustic telemetry systems. This decreases the likelihood of signal collision due to multipath signals from highly reflective structures such as intake walls and water surfaces. It also has a high carrier frequency, which is critical because background noise at environments close to dams is greater at lower frequency ranges. The experimental design to address the critical uncertainties will be developed in collaboration with Dr. John Skalski at the University of Washington. Although the virtual/paired-release model has been recognized as the regional standard and has been described in detail, there will be instances where the specifics of how it is implemented must be refined for application to juvenile lamprey because of the unique characteristics of each dam and juvenile lamprey.

Task 3. Conduct preliminary field trial

Final priority study locations will be selected through discussions with regional managers and stakeholders. We propose to deploy three autonomous receiver arrays from downstream of McNary Dam to upstream of John Day Dam (Figure 3). The autonomous receivers will be anchored 2 to 5 meters above the river bottom (Titzler et al. 2010) and provide a detection history that includes accepted tag detections for all times and locations where receivers were operating. The detection histories will then be used to estimate the detection probability and number of detections.

We will also deploy additional receivers at one of three arrays to assess the feasibility of extracting 3D behavior of the tagged lampreys. Controlled field testing including fixed-location tests and drogue drift tests will be conducted close to the receiver array with additional receivers. The lamprey tags will be attached to a remote controlled boat and placed at different water depths. For the fixed-location tests, the tags will be held at various locations in slant range from 5 m to 100 m horizontal range from the array. For the drogue drift test, the tags will travel across the region following various trajectories from several release locations. The locations of the tags for all test cases will be obtained through a real-time kinematic GPS system and depth sensor, which will provide benchmark measurements for comparison with the 3D-tracked locations. The accuracy will be assessed in terms of median and root mean square (RMS) values of the differences between GPS measurements and 3D-tracked locations, similar to Figure 4 for a cabled array mounted to a dam face.

About 100 juvenile Pacific lamprey will be tagged near the mouth of the Umatilla River for this preliminary pilot trial. We will work with Aaron Jackson of the Confederated Tribes of the Umatilla Indian Reservation for the fish collection. A backup option is to collect and tag fish at McNary Dam. All the tags will be manufactured at PNNL in-house facilities.

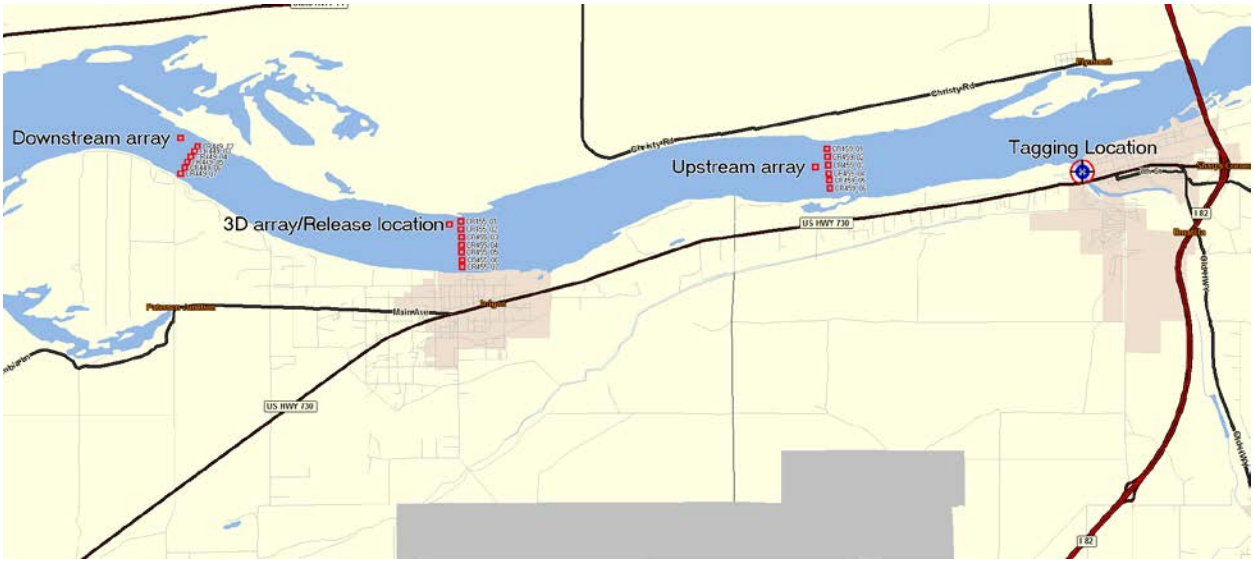

Figure 3 Map displaying locations of one design option for fish releases and autonomous receiver arrays

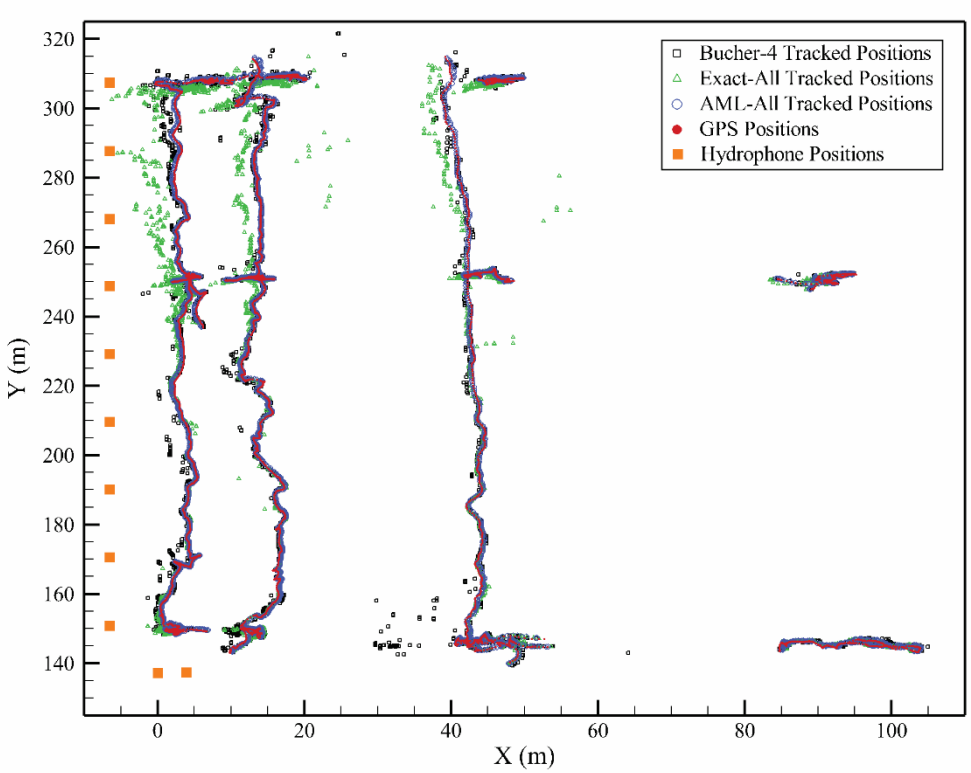

Figure 4: Comparison of GPS-measured positions and 3D-tracked positions at Little Goose Dam spillway using various localization solvers.

Task 4 Additional Data collection (optional)

This task is optional. It covers an additional 3-week deployment and data collection in addition to the 6-week data collection covered under Task 3. While the expected tag life of the new lamprey eel tag is 20 to 30 day, there is a chance that some tags will last longer. In addition, the additional 3-week data collection period may be needed to mitigate the uncertainties of fish collection.

Task 5 Conduct a full scale study in 2018 (Placeholder)

Based on findings of the pilot field trial in 2017 and the RME plan, we will plan to conduct a full scale field study in 2018, as funding and resources allow.

C. Facilities and Equipment

PNNL has all of facilities and most of the equipment required for this project.

D. Impacts

Access to the project and sampling areas will be required. We will coordinate closely.

E. Schedule

A final work schedule will be developed collaboratively during the initial pre-work meeting, after the contract has been awarded. Preparatory work will begin on the date that the contract is awarded. PNNL will prepare and deliver a presentation describing the methods and preliminary results at the Annual Anadromous Fish Evaluation Program meeting to be held in Walla Walla, WA in late November or early December 2017. A draft report will be prepared and delivered no later than January 31, 2018. A final report incorporating changes to the draft report resulting from regional review will be submitted no later than March 31, 2018. Modifications of these delivery schedules may be implemented after discussions with the USACE technical points of contact (Ricardo Walker and Steve Juhnke).

IV. List of Key Personnel and Project Duties

Name (Affiliation)	Duties
Z. Daniel Deng, Ph.D. (PNNL)	Principal Investigator
Bob Mueller (PNNL)	Co- Principal Investigator, fish collection and tagging
Alison Colotelo (PNNL)	Co- Principal Investigator, study design and fish physiology
Huidong Li, Ph.D. (PNNL)	Tag manufacturing
Mitchell Myjak, Ph.D. (PNNL)	Tag manufacturing-Electronics
Yong Yuan, Ph.D. (PNNL)	Equipment and Tag acceptance testing
Jason Zhang, Ph.D. (PNNL)	Tag manufacturing-Microbattery
Jayson Martinez (PNNL)	Field study coordinator
Scott Titzler (PNNL)	Receiver deployment
Xinya Li, Ph.D. (PNNL)	3D tracking
John Skalski, Ph.D. (UW)	Statistical study design

V. Technology Transfer

Information acquired during the proposed work will be transferred in the form of a technical document detailing the methods and preliminary results at the Annual Anadromous Fish Evaluation Program meeting. A draft and final report will also be prepared and delivered. In addition, results could be presented at regional or annual American Fisheries Society Meetings, at another related domestic conferences, or submitted to peer-reviewed journals.

VI. Literature Cited

Close, D., Fitzpatrick, M.S., Li, H.W., Parker, B., Hatch, D., and G. James. 1995. Status report of the Pacific lamprey (Lampetra tridentata) in the Columbia River Basin. Report to the Bonneville Power Administration, Contract 95BI39067, Portland, OR.

Colotelo AHA, BD Pflugrath, RS Brown, CJ Brauner, RP Mueller, TJ Carlson, Z Deng, ML Ahmann, and BA Trumbo. 2012. "The effect of rapid and sustained decompression on barotrauma in juvenile brook lamprey and Pacific lamprey: implications for passage at hydroelectric facilities." Fisheries Research 129-130:17-20. doi:10.1016/j.fishres.2012.06.001

Deng Z, TJ Carlson, H Li, J Xiao, MJ Myjak, J Lu, JJ Martinez, CM Woodley, MA Weiland, and MB Eppard. 2015. "An injectable acoustic transmitter for juvenile salmon." Scientific Reports 5:8111. doi:10.1038/srep08111

Deng Z, MA Weiland, T Fu, TA Seim, BL Lamarche, EY Choi, TJ Carlson, and MB Eppard. 2011. "A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 2. Three-Dimensional Tracking and Passage Outcomes." Sensors 11(6):5661-5676.

Dauble DD, RA Moursund, and MD Bleich. 2006. "Swimming behaviour of juvenile Pacific lamprey, Lampetra tridentata." Environmental Biology of Fishes 75(2):167-171.

Ingraham JM, Z Deng, X Li, T Fu, GA McMichael, and BA Trumbo. 2014a. "A fast and accurate decoder for underwater acoustic telemetry." Review of Scientific Instruments 85(7):074903.

Ingraham JM, Z Deng, JJ Martinez, BA Trumbo, RP Mueller, and MA Weiland. 2014b. "Feasibility of Tracking Fish with Acoustic Transmitters in the Ice Harbor Dam Tailrace." Scientific Reports 4:Article Number 4090. doi:10.1038/srep04090

Jung, K. W., Deng, Z. D., Martinez, J. J., Geist, D. R., McMichael, G. A., Stephenson, J. R., & Graf, P. J. (2015). Performance of an acoustic telemetry system in a large fishway. Animal Biotelemetry, 3(1), 1-9.

Li X, Z Deng, RS Brown, T Fu, JJ Martinez, GA Mcmichael, JR Skalski, RL Townsend, BA Trumbo, ML Ahmann, and JF Renholods. 2015a. "Migration Depth and Residence Time of Juvenile Salmonids in the Forebays of Hydropower Dams Prior to Passage through Turbines or Juvenile Bypass Systems: Implications for Turbine Passage Survival." Conservation Physiology 3(1):Article No. cou064. doi:10.1093/conphys/cou064

Li X, Z Deng, JJ Martinez, T Fu, PS Titzler, JS Hughes, MA Weiland, RS Brown, BA Trumbo, ML Ahmann, and JF Renholods. 2015b. "Three-Dimensional Tracking of Juvenile Salmon at Mid-Reach Location between Dams." Fisheries Research 167:216-224. doi:10.1016/j.fishres.2015.01.018

Li X, Z Deng, RS Brown, T Fu, JJ Martinez, GA Mcmichael, JR Skalski, RL Townsend, BA Trumbo, ML Ahmann, and JF Renholods. 2015c. "Migration Depth and Residence Time of Juvenile Salmonids in the Forebays of Hydropower Dams Prior to Passage through Turbines or Juvenile Bypass Systems: Implications for Turbine Passage Survival." Conservation Physiology 3(1):Article No. cou064. doi:10.1093/conphys/cou064

Li X, Z Deng, Y Sun, JJ Martinez, T Fu, GA McMichael, and TJ Carlson. 2014. "A 3D approximate maximum likelihood solver for localization of fish implanted with acoustic transmitters." Scientific Reports 4:Article number: 7215. doi:10.1038/srep07215

Kareiva, P., Marvier, M., and M. McClure. 2000. Recovery and management options for spring/summer chinook salmon in the Columbia River Basin. Science 290:977–979.

McMichael GA, MB Eppard, TJ Carlson, JA Carter, BD Ebberts, RS Brown, MA Weiland, GR Ploskey, RA Harnish, and Z Deng. 2010. "The Juvenile Salmon Acoustic Telemetry System; A New Tool." Fisheries 35(1):9-22.

Mesa, MG, LK Weiland, HE Christiansen, and CA Peery. 2015. "SYNTHESIS OF JUVENILE LAMPREY MIGRATION AND PASSAGE RESEARCH AND MONITORING AT COLUMBIA AND SNAKE RIVER DAMS". Report for US Army Corps of Engineers.

Moursund RA, DD Dauble, and M Langeslay. 2003. "Turbine Intake Diversion Screens: Investigating Effects on Pacific Lamprey." Hydro Review XXII(1):40-46.

Moser, M.L A.D. Jackson, M.V. Lucas, and R.P Mueller. 2015. Behavior and potential threats to survival of migrating lamprey ammocoetes and macrophthalmia. Rev Fish Biol Fisheries (2015) 25:103–116, DOI 10.1007/s11160-014-9372-8.

Mueller RP, RA Moursund, and MD Bleich. 2006. "Tagging Juvenile Pacific Lamprey with Passive Integrated Transponders: Methodology, Short-Term Mortality, and Influence on Swimming Performance." North American Journal of Fisheries Management 26(2):361-366.

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and Columbia rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

Titzler PS, GA McMichael, and JA Carter. 2010. "Autonomous Acoustic Receiver Deployment and Mooring Techniques for Use in Large Rivers and Estuaries." North American Journal of Fisheries Management 30(4):853-859. doi:10.1577/M09-143.1

Weiland MA, Z Deng, TA Seim, BL Lamarche, EY Choi, T Fu, TJ Carlson, AI Thronas, and MB Eppard. 2011. "A cabled acoustic telemetry system for detecting and tracking juvenile salmon: Part 1. Engineering design and instrumentation." Sensors 11(6):5645-5660.

VII. Budget

The budget will be submitted under separate cover.