Pacific Northwest
NATIONAL LABORATORY

PNNL-36993

Optimization and Commercialization of the Juvenile Eel/Lamprey Acoustic Transmitter and Micro-battery

CRADA 477 (PNNL 75971/78761)
November 2024

Daniel Deng
Huidong Li
Jun Lu
Bingbin Wu

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99354

Cooperative Research and Development Agreement (CRADA) Final Report

Report Date:

In accordance with Requirements set forth in the terms of the CRADA, this document is the CRADA Final Report, including a list of Subject Inventions, to be provided to PNNL Information Release who will forward to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research. **PNNL acknowledges that the CRADA parties have been involved in the preparation of the report or reviewed the report.**

Parties to the Agreement:

Battelle

Innovasea Systems

Advanced Telemetry Systems

Yakama Nation Fisheries

California Department of Water Resources

CRADA number: 477

CRADA Title: Optimization and Commercialization of the Juvenile Eel/Lamprey Acoustic Transmitter and Micro-battery

Responsible Technical Contact at DOE Lab(PNNL): Daniel Deng

Name and Email Address of POC at Partner Company(ies):

Sponsoring DOE Program Office(s): OTT, WPTO

Provide a list of publications, conference papers, or other public releases of results, developed under this CRADA:

Abstracts

1. Deng Z., H. Li, J. Lu, B. Wu, J.J. Martinez, J. Xiao, and R.P. Mueller, et al. 05/06/2024. "Next-Generation Miniature Transmitter Development for Fish Passage Monitoring." Abstract submitted to The 15th International Symposium on Ecohydraulics (ISE 2024) and Fish Passage, Québec City, Canada. PNNL-SA-192444.
2. Deng Z., H. Li, J. Lu, B. Wu, J.J. Martinez, J. Xiao, and R.P. Mueller, et al. 12/05/2023. "Next-Generation Miniature Transmitter Development for Fish Passage Monitoring." Abstract submitted to 2023 Joint Meeting of EPRI's Anguillid Eel Interest Group (AEIG) and the Sturgeon Interest Group (SIG), Québec City, United States. PNNL-SA-192878.
3. Deng Z., H. Li, J. Lu, B. Wu, J.J. Martinez, J. Xiao, and R.P. Mueller, et al. 04/29/2024. "Next-Generation Miniature Transmitter Development for Fish Passage Monitoring." Abstract submitted to 2024 American Fisheries Society WA-BC-Idaho Joint Meeting, Spokane, Washington. PNNL-SA-195262.

Journal Articles

1. Haas T., T.R. Castro-Santos, S.M. Miehls, Z. Deng, T.M. Bruning, and C.M. Wagner. 2023. "Survival, healing, and swim performance of juvenile migratory sea lamprey (*Petromyzon marinus*) implanted with a new acoustic microtransmitter designed for small eel-like fishes." Animal Biotelemetry 11. doi:10.1186/s40317-023-00318-1.
2. Haas T., T. Brenden, Z. Deng, and C.M. Wagner. 2024. "Evaluation of survival estimates generated from tracking downstream migrating juvenile sea lamprey (*Petromyzon marinus*) with a miniature acoustic telemetry tag." Canadian Journal of Fisheries and Aquatic Sciences 81, no. 4:403 - 416. doi:10.1139/cjfas-2023-0194.
3. Jepsen N., L. Richter, M. Pedersen, and Z. Deng. 2022. "Survival, growth and tag retention of juvenile European eel (Anguilla anguilla L.) with implanted 12 mm Passive Integrated Transponder tags and Acoustic tags." Journal of Fish Biology 101, no. 5:1375-1380. PNNL-SA-170726. doi:10.1111/jfb.15183
4. Wu B., H. Ouro-Koura, S. Lu, H. Li, X. Wang, J. Xiao, and Z. Deng. 2023. "Functional Materials for Powering and Implementing Next-Generation Miniature Sensors." Materials Today 69. PNNL-SA-186034. doi:10.1016/j.mattod.2023.09.001

Presentations

1. Deng Z. 02/02/2024. "Biotelemetry and Autonomous Sensing Technologies for Supporting the Design and Operations of Environmentally Friendly Renewable Energy Systems." Presented by Z. Deng at University of Houston, BEYER DISTINGUISHED LECTURE SERIES, Houston, Texas. PNNL-SA-194519.

2. Deng Z. 11/30/2023. "Next-Generation Acoustic Transmitter Development for Fish Passage Monitoring." Presented by Z. Deng at 2023 Joint Meeting of EPRI's Anguillid Eel Interest Group (AEIG) and the Sturgeon Interest Group (SIG), Online Conference, California. PNNL-SA-192961.

3. Deng Z., H. Li, J. Lu, B. Wu, J.J. Martinez, J. Xiao, and R.P. Mueller, et al. 01/22/2024. "Next-Generation Miniature Transmitter Development for Fish Passage Monitoring." Presented by Z. Deng at 2023 Anadromous Fish Evaluation Program Annual Review, The Dalles, Oregon, Oregon. PNNL-SA-194227.

News media

1. The ELAT appeared in a news article published by Northwest Public Broadcasting, titled "Scientists use tiny tags to learn how young lamprey travel through dams" (https://www.nwpb.org/2022/07/26/scientists-use-tiny-tags-to-learn-how-young-lamprey-travel-through-dams/)

Technical reports (related but not under the CRADA)

1. Deng Z., K.A. Deters, J.J. Martinez, R.A. Harnish, R.P. Mueller, P. Titzler, and H. Li, et al. 2024. Juvenile Pacific Lamprey Passage Behavior and Survival at Lower Granite Dam and Lower Monumental Dam, 2023. PNNL-36195. Richland, WA: Pacific Northwest National Laboratory.
2. Deng Z., K.A. Deters, J.J. Martinez, R.A. Harnish, R.P. Mueller, P. Titzler, and T. Fu, et al. 2023. Juvenile Pacific Lamprey Passage Behavior and Survival at Lower Granite Dam, 2022. PNNL-34285. Richland, WA: Pacific Northwest National Laboratory.

Provide a detailed list of all subject inventions, to include patent applications, copyrights, and trademarks:

No subject inventions were generated under this CRADA.

Executive Summary of CRADA Work

Through collaboration with partners under this CRADA, we continued to optimize the Eel/Lamprey Acoustic Transmitter (ELAT) of the Juvenile Salmon Acoustic Telemetry System (JSATS) to enhance its capability to track sensitive species and early life stages of fish with 3D and sub-meter accuracy. The transmitter firmware was improved to offer new functionalities, and the circuit design was revised to provide significantly more accurate frequency transmission. The transmitter's transducer was replaced with a shorter, more energy-efficient model. Additionally, the manufacturing processes for the transmitter and the microbattery used in it were improved. The outcomes of this work help advance understanding of migration timing and behaviors, habitat use, and survival rates of these species, supporting more informed management decisions for new and existing hydroelectric facilities and better designs for new hydropower systems that minimize or avoid environmental impacts.

Summary of Research Results

Summary of key technical achievements from this CRADA:

1. An enhanced version of ELAT firmware was developed. Incorporating two new functions:
    - **Hibernation**: his function enables the transmitter to enter a deep sleep mode for a specified period before starting transmission. This flexibility allows the user to preserve the limited service life of the ELAT during times when detecting tagged fish is unnecessary, or when tagged fish are not near the detection arrays.
    - **Battery voltage readout**: This function allows the transmitter to report its battery voltage in the form of a JSATS tag code. The micro-battery voltage is a reliable indicator of battery health. Detecting an abnormally low voltage in a new transmitter can help identify potential battery failures before implantation in fish. Additionally, this feature provides tag manufacturers with a method to screen for potentially defective transmitters during production.

2. The length of the transducer used in the transmitter was reduced from 3.4 mm to 3.3 mm, resulting in approximately 10–20% lower energy consumption during transmission without compromising acoustic performance. The slightly shorter transducer also simplifies assembly by improving accessibility to components within the transducer, making it easier to attach to the ELAT's circuit board.

3. We published an online paper on the feasibility of studying European eels using ELAT.

4. In collaboration with Michigan State University and other researchers, we coauthored two papers on tagging and studying juvenile sea lamprey with ELAT. This feasibility evaluation served as a basis for the graduate student's MS thesis research at Michigan State University.

5. We collaborated with a graduate student and their advisor at Bowling Green State University to evaluate the feasibility of studying crayfish using ELAT.

6. We conducted a trial production run of prototypes for the Gen 2 micro-battery, which incorporated a modified cathode with bounded powder. A new reliable sealing process was also developed.

7. We optimized the ELAT encapsulation method in the manufacturing process. A new 3D-printed "push pen" tool was created to precisely control the positioning of the transmitter within the encapsulation mold cavity. This improvement results in a consistent epoxy coating at the transducer end of the transmitter, reducing the need for sanding and polishing after encapsulation.

8. The optimized ELAT was used in multiple U.S. Army Corps of Engineers lamprey tracking studies in the Pacific Northwest (at Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam). These studies investigated the forebay behavior and primary passage routes of juvenile Pacific lamprey, as well as estimating their dam passage and reach survival rates.

9. The optimized ELAT was used by the Bureau of Reclamation and the U.S. Geological Survey (USGS) for a multi-year study to evaluate the migration survival of juvenile chinook salmon below Irongate Dam in the Lower Klamath River

10. The optimized ELAT was used by the California Department of Water Resources to study migrating salmon in the Sacramento Delta.

11. PNNL was part of a pilot effort to track outmigration of sea lampreys as they seek their first host in the Great Lakes. Partners include USGS, University of Michigan-Flint, Michigan Tech's Great Lakes Research Center, Michigan State University, USFWS, Fisheries and Oceans Canada

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