PNNL-37002

Optimize the Autonomous Sensor Fish Device for Understanding Interactions of Aquatic Animals with Marine and Hydrokinetic and Hydro Systems (CRADA 476) Final Report

November 2024

Daniel Deng
Aljon L Salalila
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Jayson J Martinez
Hongfei Hou

U.S. DEPARTMENT OF ENERGY

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

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Pacific Northwest National Laboratory
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 Memorial Institute

Natel Energy, Inc.

Electric Power Research Institute, Inc.

Advanced Telemetry Systems

CRADA number: 476

CRADA Title: Optimize the Autonomous Sensor Fish Device for Understanding Interactions of Aquatic Animals with Marine and Hydrokinetic and Hydro Systems

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Advanced Telemetry Systems: Peter Kuechle (pkuechle@atstrack.com)

Sponsoring DOE Program Office(s): N/A

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

Abstracts

1. Salalila A.L., Z. Deng, C. Tian, J.J. Martinez, R.P. Mueller, O. Phonekhampheng, and D. Singhanouvong, et al. 10/08/2021. "In situ characterization of hydraulic environment to support development of fish-friendly hydropower guidelines and sustainable irrigation in the lower Mekong River region." Abstract submitted to 2021 Sino-American Youth Dialogue on Climate Change, Online Conference, China. PNNL-SA-166810.

2. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 03/03/2024. "Advancing the Autonomous Sensor Fish: Unlocking Insights into Aquatic Animal Interactions with Marine and Hydrokinetic Systems." Abstract submitted to 9th World Fisheries Congress, Seattle, Washington. PNNL-SA-186931.

3. Romero-Gomez P., Z. Deng, R. Peyreder, and L.J. Baumgartner. 05/06/2024. "Combining Sensor- and Simulation-based Assessments of Fish Passage through Hydro Turbines." Abstract submitted to The joint ISE – Fish Passage 2024 conference, Québec City, Canada. PNNL-SA-191892.

4. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, H. Li, and Z. Deng. 2023. "Development of the Sensor Fish Suites for Hydropower and Marine Hydrokinetic Technologies." In The 15th International Symposium on Ecohydraulics (ISE 2024) and Fish Passage. PNNL-SA-192273.

5. Romero-Gomez P., Z. Deng, and R. Peyreder. 06/13/2022. "Fish-related Performance Evaluation of Turbines in Industry Settings." Abstract submitted to Fish Passage 2022 – the International Conference on River Connectivity, Richland, Washington. PNNL-SA-171623.

6. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 10/07/2024. "Design and Application of Marine Sensor Fish for Marine Energy Technologies." Abstract submitted to CLEAN CURRENTS, Portland, Oregon. PNNL-SA-195423.

7. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, H. Li, W. Hwang, and Z. Deng. 09/15/2024. "Development of the Sensor Fish Suites for Hydropower and Marine Hydrokinetic Technologies." Abstract submitted to American Fisheries Society 154th Annual Meeting, Honolulu, Hawaii. PNNL-SA-198269.

8. Romero-Gomez P., Z. Deng, and R. Peyreder. 11/18/2024. "Comparative Study of Fish Passage Conditions via Test Rig Experiments: Propeller vs. Double-Regulated Kaplan Turbines." Abstract submitted to HYDRO 2024, Graz, Austria, Austria. PNNL-SA-197058.

Conference Paper

1. Romero-Gomez P., A.L. Salalila, Z. Deng, and R. Peyreder. 2022. "Evaluation of Fish-Related Properties of Kaplan Turbines at the Design Phase: Simulation-based outcomes vs. Experimental Data." In IAHR 31st Symposium on Hydraulic Machinery and Systems (IAHR 2022), June 26-July 1, 2022, Trondheim, Norway. IOP Conference Series: Earth and Environmental Science, 1079, Paper No. 012016. PNNL-SA-170836. doi:10.1088/1755-1315/1079/1/012016

Journal Article

1. Salalila A.L., J.J. Martinez, A.L. Tate, N.F. Acevedo, M. Salalila, and Z. Deng. 2023. "Balloon Tag Manufacturing Technique for Sensor Fish and Live Fish Recovery." Journal of Visualized Experiments (JoVE) 2023, no. 200:Art. No. e65632. PNNL-SA-182890. doi:10.3791/65632

2. Romero-Gomez P., A.L. Salalila, Z. Deng, and R. PEYREDER. 2024. "Feasibility study for test rig assessments of fish passage conditions in a Kaplan turbine." Heliyon 10, no. 5:Art. No. e26846. PNNL-SA-170427. doi:10.1016/j.heliyon.2024.e26846

3. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 2024. "Autonomous Sensor Suite for Evaluating Fish-Turbine Interactions and Environmental Impacts in Marine Renewable Energy and Hydropower." IEEE Journal of Oceanic Engineering. PNNL-SA-204684. [Unpublished]

Software

1. Hou H., J. Lu, A.L. Salalila, and Z. Deng. 2024. "Sensor Fish Communicator for Marine & Hydrokinetic." PNNL-SA-195273.

Presentations

1. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 05/06/2024. "Development of the Sensor Fish Suites for Hydropower and Marine Hydrokinetic Technologies." Presented by Z. Deng at Fish Passage, Qeubec, Canada. PNNL-SA-198127.

2. Romero-Gomez P., Z. Deng, R. Peyreder, and L.J. Baumgartner. 05/08/2024. "SENSOR AND SIMULATION BASED ASSESSMENTS FOR TURBINE PASSAGE." Presented by P. Romero-Gomez at The 15th International Symposium on Ecohydraulics and Fish Passage, Quebec City, Canada. PNNL-SA-198247.

3. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 09/17/2024. "Development of the Sensor Fish Suites for Hydropower and Marine Hydrokinetic Technologies." Presented by A.L. Salalila at American Fisheries Society 154th Annual Meeting, Honolulu, Hawaii. PNNL-SA-203508.

4. Salalila A.L., J. Lu, J.J. Martinez, H. Hou, and Z. Deng. 03/05/2024. "Advancing Autonomous Sensor Fish for Hydropower and Marine Hydrokinetic Technologies." Presented by J. Lu at 9th World Fisheries Congress, Seattle, Washington. PNNL-SA-195526.

5. Deng Z. 03/01/2023. "Sensing Technologies for Environmentally Friendly Water Power Systems." Innovation Engine for Digital Urban & Rural Equity (iEnDURE) Symposium. Seattle, Washington. PNNL-SA-182319.

6. Deng Z., T. Fu, J. Wang, J.J. Martinez, and T.R. Edwards. 12/05/2023. "Metrics for Predicting Fish Survival Using Autonomous Sensor Fish." Presented by Z. Deng at Canadian Science Advisory Secretariat Science Peer Review Meetings, Online Conference, Online, Canada. PNNL-SA-193145.

7. Deng Z., T. Fu, J. Wang, J.J. Martinez, and T.R. Edwards. 02/07/2022. "Metrics for Predicting Fish Survival Using Autonomous Sensor Fish." Presented by Z. Deng at Technical University of Munich, Online, Germany. PNNL-SA-170159.

8. Salalila A.L., Z. Deng, C. Tian, J.J. Martinez, R.P. Mueller, O. Phonekhampheng, and D. Singhanouvong, et al. 10/07/2021. "In situ characterization of hydraulic environment to support development of fish-friendly hydropower guidelines and sustainable irrigation in the lower Mekong River region." Zoom, Washington. PNNL-SA-167539.

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

This project at the Pacific Northwest National Laboratory (PNNL) enhances our understanding of how aquatic life interacts with marine renewable energy (MRE) and hydropower systems through the development and testing of advanced sensor technology. The Marine Sensor Fish (MSF) and its smaller variants, the Sensor Fish Mini (SF Mini) and Flexible Sensor Fish (FSF), measure critical environmental stressors, such as shear forces, pressure changes, and strike impacts, that are essential for assessing the risks posed by energy devices, including tidal turbines, hydropower installations, and other MRE infrastructure. Rigorous field testing has shown that these tools are effective in capturing detailed data on turbulence, pressure variations, strike impacts, and other stressors near these devices, providing valuable insights into the conditions faced by aquatic species. Economically, these tools offer renewable energy developers a practical solution for streamlining environmental assessments and ensuring regulatory compliance, ultimately reducing costs associated with evaluating and mitigating ecological impacts. This research also benefits the public by promoting the growth of renewable energy sources that protect aquatic ecosystems, advancing both sustainable energy production and environmental stewardship.

Summary of Research Results

Pacific Northwest National Laboratory (PNNL) developed advanced sensor technology to monitor and assess fish interactions with marine renewable energy (MRE) systems and hydropower infrastructure. This effort focused on creating and testing three sensor devices: the Marine Sensor Fish (MSF), Sensor Fish Mini (SF Mini), and Flexible Sensor Fish (FSF), each designed to measure environmental stressors such as shear forces, pressure changes, and strike impacts experienced by fish near operational turbines. The overarching hypothesis was that fish encounter specific environmental stressors near MRE systems, with these stressors varying by device type and scale. The project aimed to validate this hypothesis, gather high-resolution data to support computational fluid dynamics (CFD) model validation, and inform fish-friendly design improvements in turbine technology, thereby contributing to sustainable energy development.

To achieve these objectives, each Sensor Fish variant was tailored to specific research needs. The MSF was optimized for tidal turbine studies and outfitted with a range of high-sensitivity sensors, including accelerometers, gyroscopes, temperature sensors, pressure sensors, magnetometers, salinity sensors, and acoustic transmitters, each capturing distinct environmental and mechanical parameters. The Sensor Fish Mini was scaled down for use in confined hydraulic models, retaining core capabilities to measure turbulence, pressure gradients, and other critical metrics in a compact form. The FSF, designed with a silicone body that mimics various fish anatomies, enabled species-specific impact studies by simulating how different species might physically interact with turbines.

The project faced several challenges throughout its duration. Parts procurement, especially during the COVID-19 pandemic, became a major obstacle due to widespread supply chain disruptions, which delayed the acquisition of critical components for each Sensor Fish device. Additionally, field permitting and logistical constraints impacted planned testing. The MSF was initially scheduled for testing at the Tanana River Hydrokinetic Test Site (TRTS) in Alaska. However, this remote location posed significant difficulties, including limited transportation options, unpredictable weather, and the need to coordinate with local authorities and stakeholders for environmental compliance. These logistical and permitting challenges led to relocating MSF testing to Sequim Bay, Washington, a more accessible site. To ensure the device's reliability in real-world conditions, design improvements were implemented, including refining housing materials and optimizing sensor placement to enhance durability in turbulent environments, supporting consistent, high-quality data collection.

Despite these challenges, the project successfully met its objectives. Early milestones included defining application ranges, establishing specifications, and finalizing designs for each sensor variant. Each device demonstrated its capability to capture high-resolution data in conditions approximating natural aquatic environments. Laboratory tests, including benchmark calibrations and shear flume tank testing, validated each device's durability and data accuracy. For example, the FSF effectively simulated strike impacts that fish encounter in high-shear environments during flume tests, providing valuable insights into potential injury risks. Additionally, testing the SF Mini in scaled fish bypass models identified specific high-risk areas for juvenile fish, guiding design adjustments to improve fish safety in these structures.

Field testing yielded valuable quantitative data, including measurements of acceleration peaks during turbine blade strikes and turbulence near MRE installations. Analysis of this data, combined with CFD model validation, identified key environmental stressors that fish may

encounter, such as increased risks of disorientation and collision in high-intensity turbulence zones. This data also contributed to model validation, supporting advancements in turbine technology to reduce ecological impact. For instance, the MSF's data on shear stress and pressure gradients collected at Sequim Bay confirmed the device's effectiveness in real-world MRE applications.

The project concluded with the successful delivery of fully functional prototypes and comprehensive design documentation for the MSF, SF Mini, and FSF, as well as field data from tests conducted in Sequim Bay, Natel Energy's facility, and the Whooshh Fish Transport System. These tools are now ready for broader deployment in both research and industry, advancing sustainable energy initiatives with a commitment to environmental stewardship.

In summary, the Sensor Fish project at PNNL provided valuable tools and data for the renewable energy sector, offering new methods to measure and mitigate potential risks to aquatic life. Each Sensor Fish variant met or exceeded its project goals, supporting the sustainable development of MRE systems while minimizing ecological impacts. The project's successes in collecting high-resolution data and validating CFD models contribute significantly to balancing energy production with environmental protection.

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