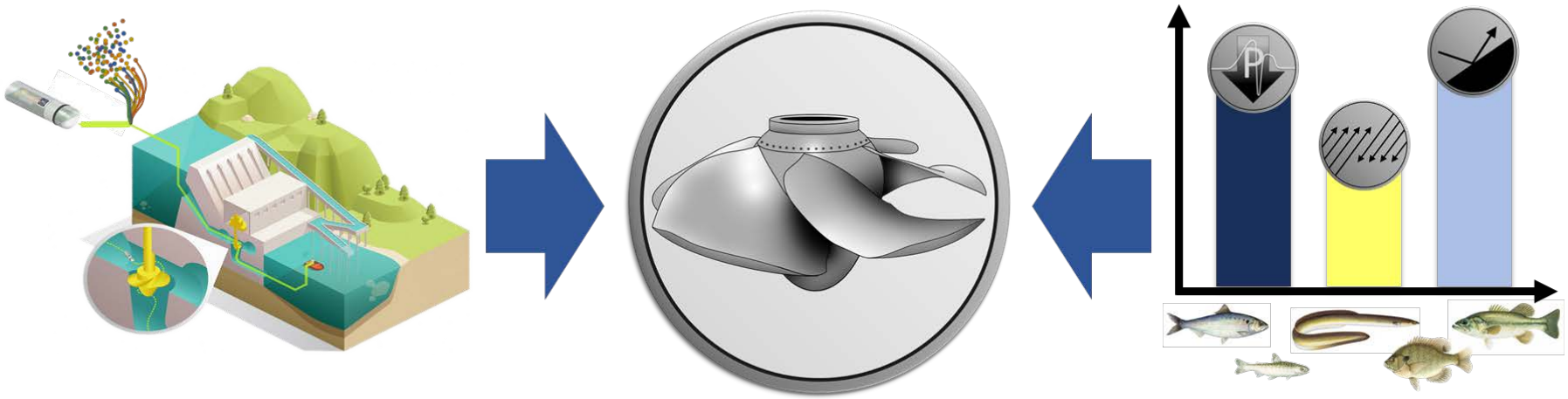


Biologically-Based Design and Evaluation of Hydropower Turbines

WBS: 1.3.1.605

Hydropower Program

October 9, 2019

Alison Colotelo

Pacific Northwest National Laboratory

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

Goal: develop, demonstrate, and transfer a suite of tools and technologies that can be used by the hydropower community to evaluate the biological performance of proposed and existing hydropower turbines.

The suite of tools includes:

- Biological Performance Assessment (BioPA)
- Hydropower Biological Evaluation Toolset (HBET), using Sensor Fish

Project Objective & Impact

Overall Objective: provide information, data, tools, and analyses that predict relative fish survival for hydropower turbines.

Impacts to the hydropower community:

- Increased fish survival rates
- Expedited regulatory review processes and reduced costs during turbine procurements and evaluations
- Increased deployments of new or rehabilitated turbines
- Increased dissemination of fundamental research (e.g., data, analyses, and information on impacts to fish).

Project Information

Project Principal Investigator(s)

Alison Colotelo & Gary Johnson, PNNL
Technical PIs:
PNNL - Marshall Richmond, Daniel Deng, Brett Pflugrath, Lara Aston
ORNL - Mark Bevelhimer, Brenda Pracheil

WPTO Lead

Dana McCoskey
Corey Vezina

Project Partners/Subs

Oak Ridge National Laboratory

Project Duration

Start Date: 10/01/2014
End Date: 9/30/2021

Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

- Technology R&D for Low-Impact Hydropower Growth
- R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet
- Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Environmental R&D and Hydrologic Systems Science

- Develop technologies and strategies that avoid, minimize, or mitigate ecological impacts
- Support development of metrics for better evaluating environmental sustainability for new hydropower developments

This project provides tools (BioPA and HBET), technologies, and information that can be used evaluate hydropower turbine designs and operations to avoid, minimize, or mitigate impacts to fish. The tools provide unique capabilities informed by datasets developed by DOE national laboratories, utilizing capabilities not available in the private sector. This work enables better evaluations of the environmental impacts of hydropower and can inform adaptive management processes and other assessments.

Project Budget

Lab	FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
	Costed	Costed	Costed	Total Costed	Total Authorized
PNNL	$985,168	$886,112	$624,955	$2,496,235	$3,930,134
ORNL	$329,711	$492,097	$247,801	$1,069,609	$1,261,387
TOTAL	$1,314,879	$1,358,209	$872,756	$3,565,844	$5,191,521

Management and Technical Approach

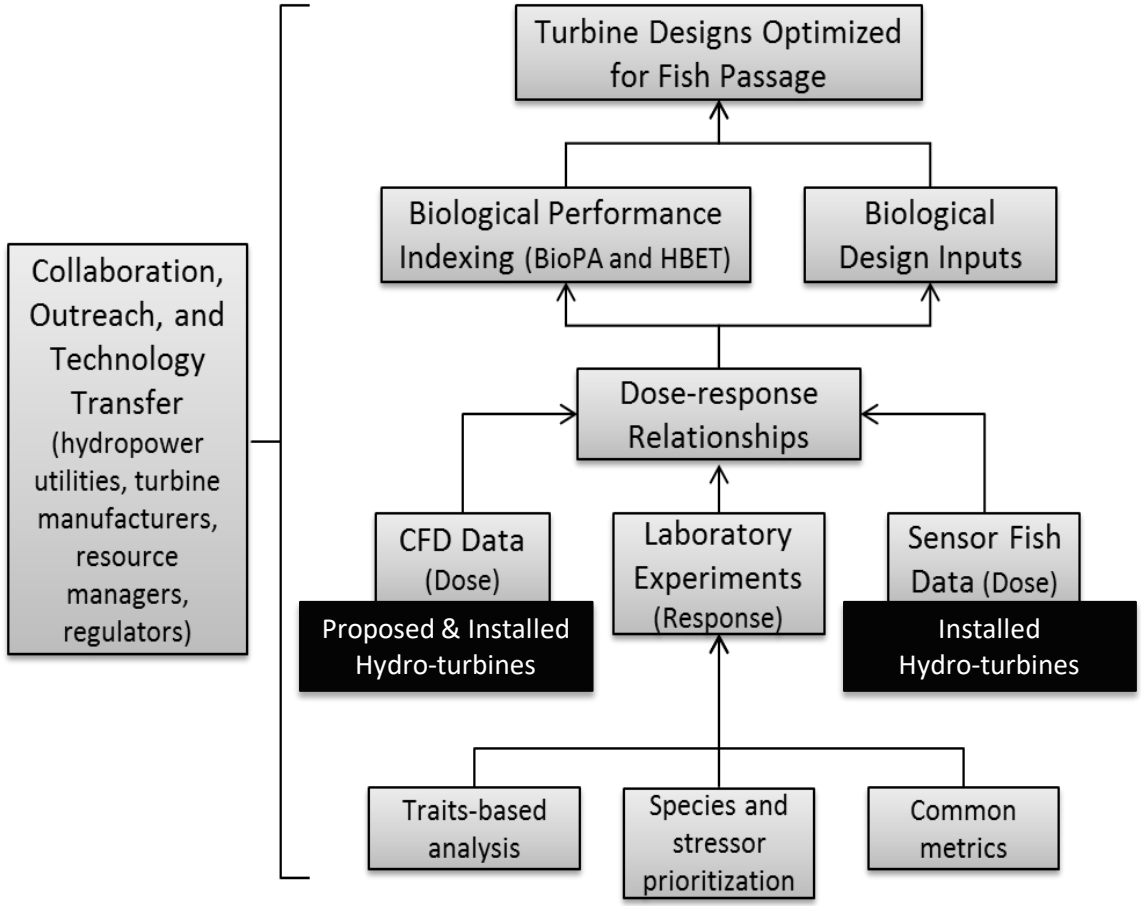
Project Technical Approach:

integrate time-series hydraulic condition data simulated with CFD models or measured using Sensor Fish with dose-response relationships generated from laboratory experiments

Four research components:

- Design
- Evaluation
- Experimentation
- Inference

Research components work in-concert to meet project goals



Management and Technical Approach - Design

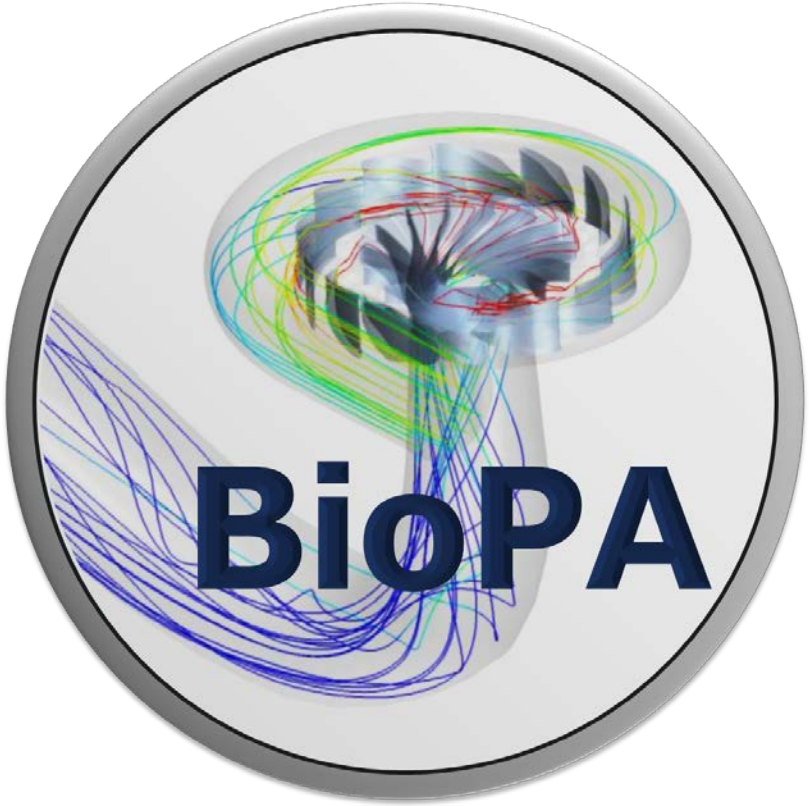
Uses data from computational fluid dynamics (CFD) simulations to calculate expected fish trajectory and resulting exposure to hydraulic biological stressors during fish passage.

CFD Simulated:

- Fish trajectory
- Pressure
- Linear acceleration
- Turbulent kinetic energy
- Flow shear

Process:

- CFD simulates the flow velocities through the turbine and used to derive trajectories of fish passage.
- CFD data is used to calculate expected stressor exposures along trajectory.
- Stressor exposures are integrated with dose-response relationships derived from experiments with live fish to determine overall biological performance.

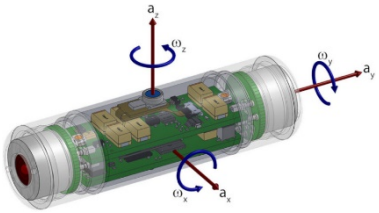


Management and Technical Approach - Evaluation

Uses Sensor Fish and other sensor data to evaluate the hydraulic and biological performance of existing, refurbished, or newly installed hydro-turbines.

Sensor Fish Measurements:

- Pressure
- Rotational velocity
- Orientation
- Linear acceleration
- Temperature



Process:

- Sensor Fish move with the flow of water through the passage route.
- Data sets are analyzed to estimate locations and frequency of events that could injure fish.
- Stressor exposures are integrated with dose-response relationships derived from experiments with live fish to determine overall biological performance.

Hydropower Biological Evaluation Toolset

Sensor Fish

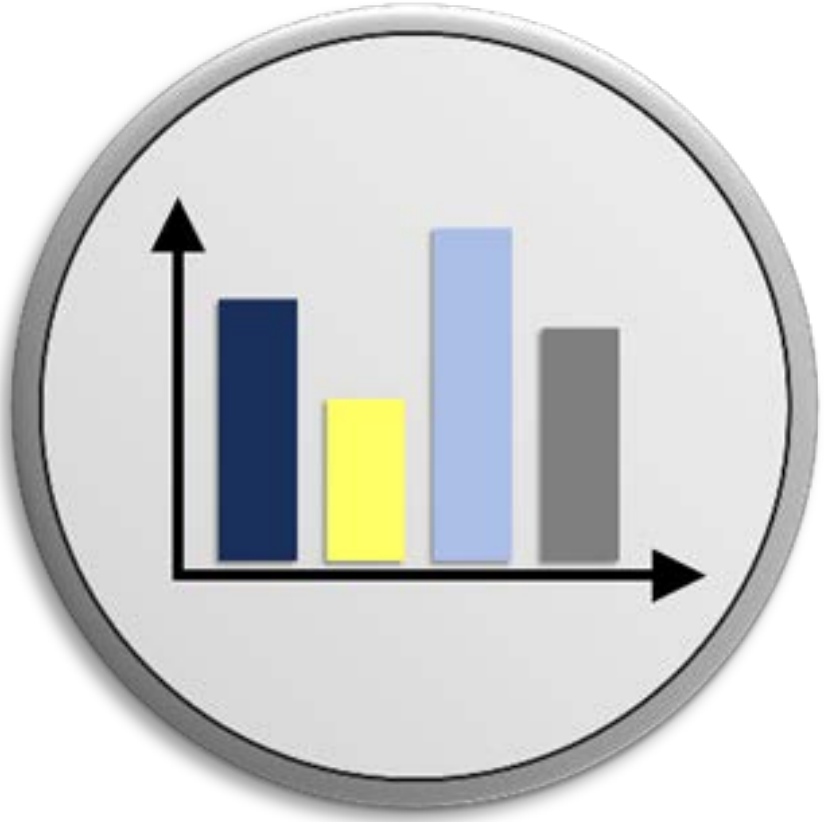
Management and Technical Approach - Experimentation

Empirically-derived dose-response relationships relate turbine passage stressors to biological response measures (i.e., injury and mortality)

Species application

- Priority species and life stages
  - Migratory
  - Conservation concern
- Assessed surrogacy potential for species with similar traits

Dose-response relationships are incorporated into BioPA and HBET to inform optimized turbine designs and operation



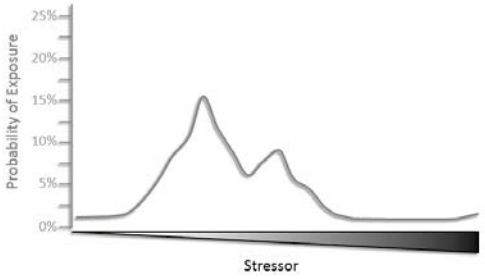
Dose-Response

Turbine Stressors and Fish Responses

Management and Technical Approach

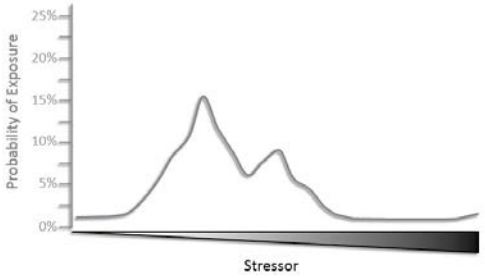
Calculate Exposure: BioPA

Simulate fish trajectories and calculate theoretical stressors as a function of time

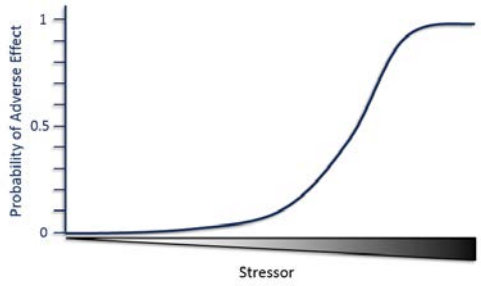


Calculate Exposure: HBET

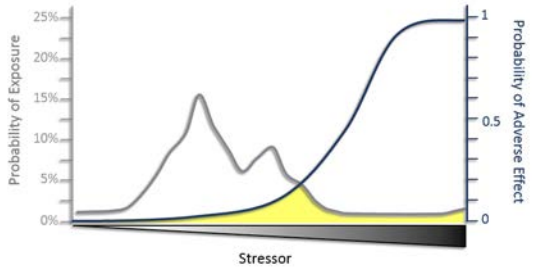
Deploy sensors to travel along fish trajectories and measure stressors as a function of time



Apply Dose-Response Relationship



Calculate Biological Performance



Management and Technical Approach - Inference

Determine statistical relationships and models that expand the application of BioPA and HBET software to a wider range of species and conditions, including potential species-specific population-level impacts

- Conduct a clustering analysis that groups species and life stages by their relative vulnerability to hydropower entrainment. Create a fish-traits database for juvenile life stages (to complement our existing adult data) of fish species of hydropower regulatory concern that includes habitat preference, movement patterns, and migratory behaviors.
- Conduct a clustering analysis that groups species based on life history traits relevant to population resilience (e.g., age at first reproduction, life-span, and fecundity) to inform relative population susceptibility and resilience to turbine (and other hydropower-related) mortality.
- Combine results of Tasks 2 and 3 into a searchable database that provides the relative risks of turbine passage and likely population-level effect for any species / life-stage combination.

End-User Engagement and Dissemination Strategy

Outreach and Collaboration Strategy

FY 2017 through Q2 FY 2019

Objectives:

1. Increase application
   - **Associated Task:**
     - Conduct direct in-person communications with turbine manufacturers, owner/operators, natural resource and regulatory agencies
2. Increase awareness
   - **Associated Tasks:**
     - Develop website – biode.labworks.org
     - Conduct one-on-one webinars with strategic member of hydropower community
     - Publish journal articles and participate in scientific meetings
3. Continue to develop coherent and consistent messaging
   - **Associated Tasks:**
     - Develop a core messaging document
     - Develop standard slide deck with branding, a logo, and templates
     - Develop guidelines to build consistency and recognition

Technical Accomplishments – Design

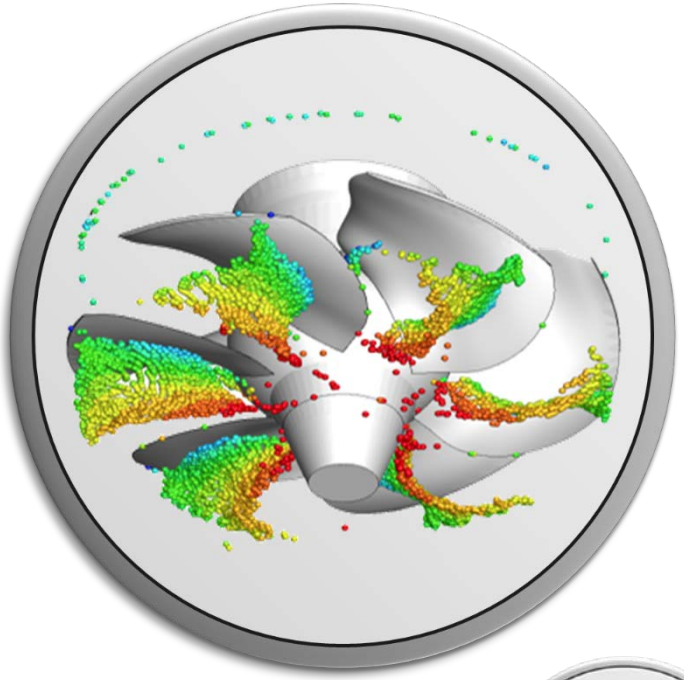
Licensed by two major turbine manufacturers

Applied at 5+ hydro facilities worldwide

BioPA	
Features	**FY 2017-18 (*V2.0*)**
Accessibility	
Small fee license available	✓
Open sourced application	
Software Required	
Requires single software package (Microsoft Excel) only	
Turbine Types Supported	
Kaplan	✓
Francis	✓
Others	
Dose-Response Relationships Available	
Dose responses added to previous version	✓
Validation with Lab/Field Studies	
Advanced fish trajectory model implemented	✓
Validation of fish trajectory model	
Improved temporal resolution of CFD calculation	

Technical Accomplishments – Design

- ✓ Transient CFD calculations for more realistic representation of the flow.
- ✓ Advances in the calculation and validation of fish trajectories from mass-less streamtraces to discrete particles for more accurate estimation of fish locations.
- ✓ Expanded dose-response capabilities for a broader application of the tool to a range of species.
- ✓ Demonstration of multiple turbine types including Kaplan, Francis, and others.
- ✓ Presentations at multiple regional and national conferences
- ✓ Publication of two peer-reviewed manuscripts:
  - Case study evaluating the modeling assumptions with datasets collected using a laboratory physical model and the Sensor Fish
  - Experimental observations to validate particle trajectory simulations



Technical Accomplishments – Evaluation

Licensed by six research and development organizations

Applied in conjunction with Sensor Fish at 30+ hydro facilities worldwide

HBET	
Features	**FY 2018 (*V1.0*)**
Accessibility	
Centralized relational database	✓
Local standalone application	
Web/Cloud based framework	
Data Types Included	
Sensor Fish	✓
Sensor Fish Mini	
JSATS	
Other technologies (balloon tagged live fish or scale-model bead data)	
Dose-Response Relationships Available	
Rapid decompression	✓
Shear	
Strike	
Dose responses added to previous version	
Statistical Analyses Available	
Statistically compare studies and design new studies	✓
More robust comparrison of treatments and studies	
Build-in data mining module	
Development of a data knowledge center	

Technical Accomplishments – Evaluation

- ✓ A local standalone version of HBET was developed to make the toolset more accessible for customers who are international users, want to privately maintain their data, or plan to use devices without internet access.
- ✓ Large data sets from previous studies have been incorporated into HBET to be used for providing references for designing new studies or for comparing to newly acquired data.
- ✓ Newly developed dose-response relationships for multiple fish species exposed to strike, shear, or pressure have been incorporated into HBET.
- ✓ The patent application filed for the Sensor Fish device was accepted by the US patent office.
- ✓ The Sensor Fish device was licensed to a commercial vendor. The vendor has developed a commercial version of Sensor Fish that has already been delivered to customers.
- ✓ A miniaturized version of Sensor Fish, known as Sensor Fish Mini, was developed that has similar measurement capabilities as the regular Sensor Fish.
- ✓ HBET and Sensor Fish have been utilized to study and help improve innovative turbine technologies that covers the study of large-scale turbines, small scale turbines, and modular hydropower.
- ✓ Presentations at multiple regional and national conferences

Technical Accomplishments – Evaluation

A total of 11 peer reviewed journal articles have been published during the peer review period. These articles featuring HBET and Sensor Fish cover topics including:

- Development of the HBET
- Review of Sensor Fish studies conducted on different Francis turbines
- Study of a large Kaplan turbine that will be replaced with a new fish friendly runner
- Studies of multiple low head hydro turbines that include an Archimedes screw turbine, a very low head turbine, a small horizontal Kaplan, and a siphon turbine
- Study using HBET and Sensor Fish to understand an existing dam with Francis turbines on the Mekong River in Laos
- Studies to investigate modifications to different spillways before and after modification
- Studies using Sensor Fish and Sensor Fish Mini to investigate fish passage structures.

Technical Accomplishments - Rapid Decompression

Rapid decompression dose-response relationships developed for 15 species

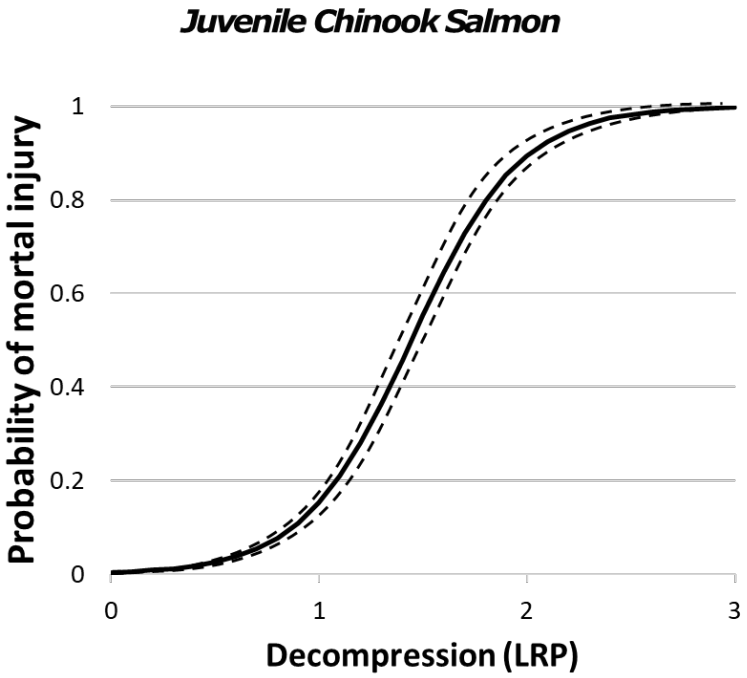
Species tested under project from 2017-2019:

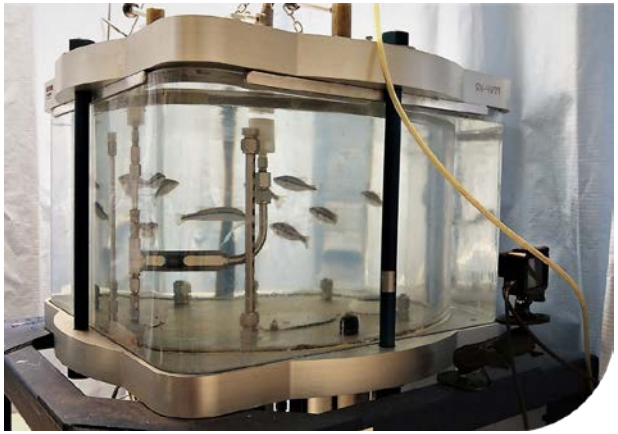
- American eel
- American shad
- Rainbow trout
- Kokanee
- Largemouth bass
- Bluegill

Data available from peer reviewed literature:

- Chinook salmon
- Pacific lamprey
- Brook lamprey
- Walleye
- Tiger muskellunge
- Australian bass
- Carp gudgeon
- Murray cod
- Silver perch

All have sufficient data for inclusion as dose-response curves in BioPA/HBET





Technical Accomplishment – Fluid Shear

Fluid shear dose-response relationships developed for nine species

Species tested under project from 2017-2019:

- American shad
- Largemouth bass
- Bluegill

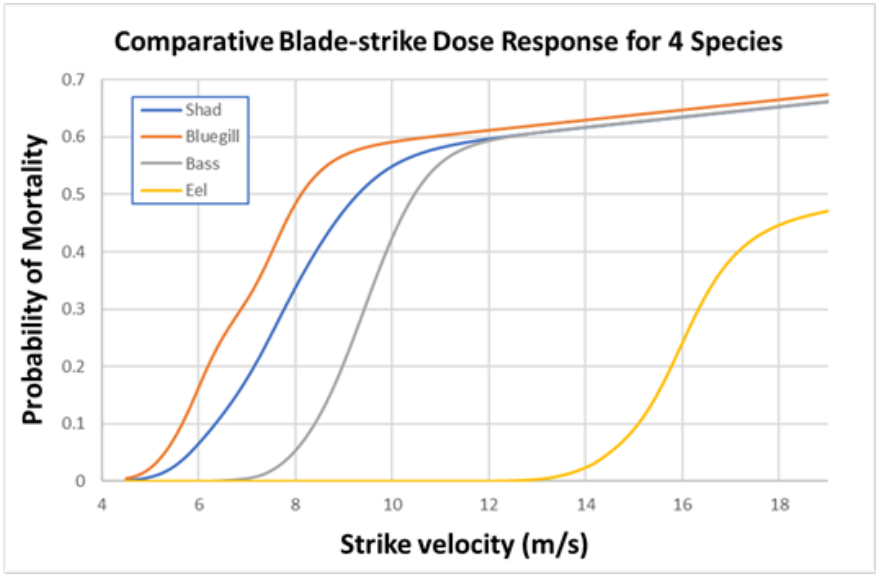
Data available from peer reviewed literature:

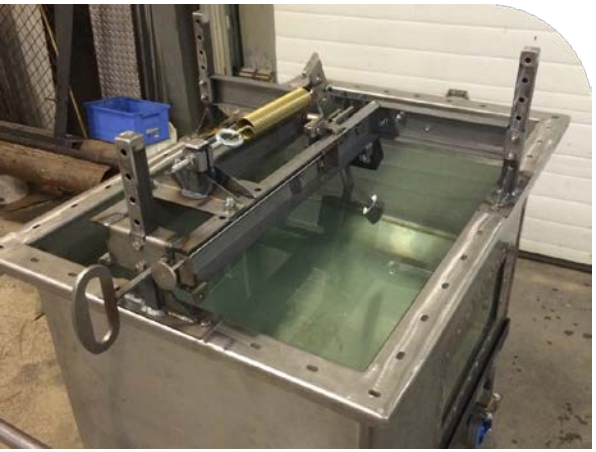
- Chinook salmon
- Steelhead
- Rainbow trout
- Blue gourami
- Iridescent shark
- Pacific Lamprey

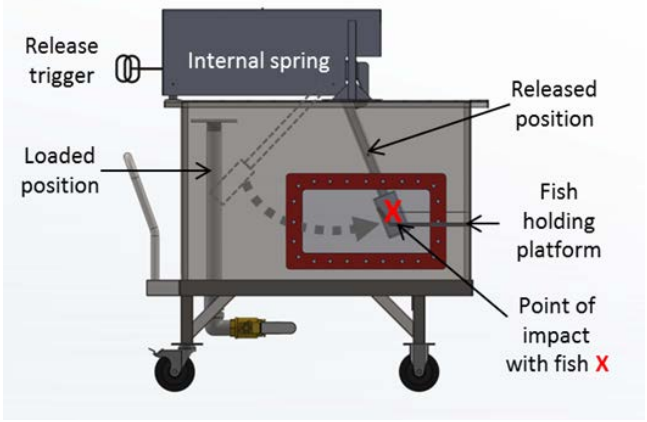
All have sufficient data for inclusion as dose-response curves in BioPA/HBET

Technical Accomplishments – Blade Strike

Blade strike dose-response relationships developed for 14 species







Species tested under project from 2017-2019:

- American eel*
- Bluegill*
- Gizzard shad*
- Hybrid striped bass*
- Paddlefish*
- Brook trout
- Rainbow trout*

Data available from other sources:

- White sturgeon*
- Atlantic herring
- Atlantic salmon
- Brown trout
- European bass
- European eel
- Sand smelt
- Whiting

*Sufficient Data for inclusion as dose-response curves in BioPA/HBET

Technical Accomplishments – Experimentation

- ✓ Completion of blade strike studies on 6 species and developing whole body dose-response equations for incorporation of results into BioPA and HBET models (ORNL lead).
- ✓ Completion of rapid decompression on 5 species for incorporation of results into BioPA and HBET (PNNL lead).
- ✓ Completion of rapid decompression on 3 species for incorporation of results into BioPA and HBET (PNNL lead).
- ✓ Evaluation of the effects of blade width, blade velocity, and strike orientation on both injury and survival (ORNL lead).
- ✓ Publication of 6 peer-reviewed manuscripts on experimental task.
- ✓ Publication of technical report comparing ORNL blade strike results and those from other labs.
- ✓ Presentations at multiple regional and national conferences.

Technical Accomplishments – Inference

- ✓ Created a juvenile fish life history database initially containing fish species of hydropower importance.
- ✓ Conducted a cluster analysis of these traits to better understand the species and traits associated with individual and population resiliency to hydropower impacts.
- ✓ Searched the literature and other databases and began to assemble a comprehensive database of life history traits (e.g., size, migratory habits, habitat preferences, and reproductive metrics) of many different fish species and life stages for the purpose of evaluating relative turbine entrainment susceptibility and relative population resilience to turbine-caused mortality.

Technical Accomplishments – Outreach

Outreach to share project updates and gain feedback from users of the tools was conducted with:

Well-known turbine manufacturers

- Voith
- Andritz
- General Electric

Other strategic partners

- US Army Corps of Engineers Hydraulic Design Center (USACE HDC)
- NOAA Fisheries

Convened symposiums

- 2017 International Conference on Engineering and Ecohydrology for Fish Passage, Corvallis, OR - Downstream fish passage
- 2018 American Fisheries Society Annual Meeting, Atlantic City, NJ - Recent advances in turbine passage research

Market Assessment

Used national datasets on turbine types, ownership and fish species of concern to help inform engagement activities for collaboration on further tool development and which direction to go with marketing the tools.

Future Work

The project has shifted to focus primarily on technology transfer of the tools to end users.

Research areas will include:

- BioPA
- HBET
- Dose-response

Emphasis and the majority of the project budget will be directed towards Hydropower Community Engagement.

Further research and development will be informed by engagement activities.

Future Work – BioPA

Expected release at the end of 2019

- Webinar in early 2020

User guide and forum for troubleshooting

BioPA		
Features	**FY 2017-18 (*V2.0*)**	**FY 2019 (*V3.0*)**
Accessibility		
Small fee license available	✓	✓
Open sourced application		
Software Required		
Requires single software package (Microsoft Excel) only		✓
Turbine Types Supported		
Kaplan	✓	✓
Francis	✓	✓
Others		
Dose-Response Relationships Available		
Dose responses added to previous version	✓	✓
Validation with Lab/Field Studies		
Advanced fish trajectory model implemented	✓	✓
Validation of fish trajectory model		✓
Improved temporal resolution of CFD calculation		✓

Future Work – HBET

Expected release at the end of 2019

- Webinar in early 2020

User guide and forum for troubleshooting

HBET		
Features	**FY 2018 (*V1.0*)**	**FY 2019 (*V2.0*)**
Accessibility		
Centralized relational database	✓	✓
Local standalone application		✓
Web/Cloud based framework		
Data Types Included		
Sensor Fish	✓	✓
Sensor Fish Mini		✓
JSATS		✓
Other technologies (balloon tagged live fish or scale-model bead data)		
Dose-Response Relationships Available		
Rapid decompression	✓	✓
Shear		✓
Strike		✓
Dose responses added to previous version		✓
Statistical Analyses Available		
Statistically compare studies and design new studies	✓	✓
More robust comparrison of treatments and studies		✓
Build-in data mining module		
Development of a data knowledge center		

Future Work – Dose-Response

Additional testing of priority species

- American eel exposed to fluid shear
- American shad exposed to blade strike

Peer-reviewed summaries on the "state of the science" for fish responses to physical turbine stressors

Future Work – Industry Engagement

- **Develop a Strategic Engagement Plan**
  - Identify most likely users of the tools and information developed under this project based on:
    - Relicensing timeline
    - Species of interest
  - Continue engagement with turbine OEMs, owner/operators, environmental consultants on the use of the tools and information
- **Engage a sub-set of potential users on needs around biological evaluation of potential and existing turbine designs**
- **Outline use cases for the tools and information developed under this project**
  - Vet use cases with hydropower community
  - Solicit suggestions for case studies to demonstrate the tools