PROGRESS TOWARDS THE NATIONAL STRATEGIC PLAN FOR AQUACULTURE RESEARCH (2023)

PREPARED BY THE

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
SUBCOMMITTEE ON AQUACULTURE
SCIENCE PLANNING TASK FORCE

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Contents

Abbreviations and Acronyms

APHIS	Animal and Plant Health Inspection Service
ARPA-E	Advanced Research Projects Agency-Energy
ARS	Agricultural Research Service
BETO	Bioenergy Technologies Office
BOEM	Bureau of Ocean Energy Management
CDC	Centers for Disease Control and Prevention
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
EERE	Office of Energy and Renewable Energy
EPA	Environmental Protection Agency
ERS	Economic Research Service
FDA	Food and Drug Administration
FSIS	Food Safety Inspection Service
FWS	Fish and Wildlife Service
HHS	Department of Health and Human Services
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NIFA	National Institute of Food and Agriculture
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
R&D	Research and Development
RMA	Risk Management Agency
SCA	Subcommittee on Aquaculture
SG	NOAA Sea Grant
U.S.	United States
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Executive Summary

U.S. aquaculture offers Americans safe, affordable, and healthy food choices produced with minimal impacts on the environment. Aquaculture is the most efficient form of animal protein production in the world and currently provides more than half of the seafood consumed globally. Conservation and fisheries organizations also depend on aquaculture for producing and restoring threatened fish species and supplementing natural reproduction of wild species of commercial and recreational importance. In addition, aquaculture producers and industries that support aquaculture such as animal feeds, health management companies, and equipment manufacturers are vital contributors to rural economies.

The National Science and Technology Council (NSTC) Subcommittee on Aquaculture's National Strategic Plan for Federal Research, published in February 2022, communicates Federal priorities for research and technology development that will facilitate responsible expansion of domestic aquaculture. This plan is foundational for supporting a science-based industry that increases seafood availability, creates jobs, and provides economic and recreational opportunities while providing for the restoration and promotion of healthy aquatic ecosystems. Federal aquaculture research programs are for the benefit of the American people, inclusive of current and future generations. This report documents collective fiscal year 2022 Federal agency progress towards the following goals and objectives of the NSTC National Strategic Plan for Federal Research.

- **Goal 1. Develop Economic Growth through Aquaculture**
  - Objective 1.1: Identify market opportunities for U.S. aquaculture products
  - Objective 1.2: Enable science-based expansion of domestic aquaculture
  - Objective 1.3: Educate and train a skilled aquaculture workforce

- **Goal 2. Improve Aquaculture Production Technologies and Inform Decision-making**
  - Objective 2.1: Provide farmers with access to improved genetics
  - Objective 2.2: Develop production technologies that minimize environmental impacts
  - Objective 2.3: Advance fish nutrition and feed production technologies
  - Objective 2.4: Improve engineering systems for aquaculture

- **Goal 3. Uphold Animal Well-Being, Product Safety, and Nutritional Value**
  - Objective 3.1: Promote strategies to protect the health and well-being of aquaculture species
  - Objective 3.2: Promote the safety and nutritional value of U.S. aquaculture products

These strategic goals are guiding Federal agencies, with public and private sector partners, to build an interagency collaborative and multidisciplinary research framework that address the Nation's aquaculture challenges.

This report summarizes notable aquaculture science activities led by Federal agencies in fiscal year 2023. Agencies that fund extramural activities have listed the subjects of awards, agencies conducting intramural activities provide a listing or narrative of their work. Additional information can be found by viewing individual agency websites or contacting agency representatives.

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Goal 1. Develop Economic Growth through Aquaculture[1]

Aquaculture provides opportunities to harness technological innovation that will increase agricultural outputs needed to provide future generations of Americans with nutritional security. This will require a skilled workforce across the Nation, including rural[2] and coastal communities. The range of economic conditions in rural and coastal communities covers the spectrum from areas that are growing and economically vibrant to areas that are economically distressed and underutilized. The economies of many rural and coastal communities are founded on the availability of abundant natural resources, and are supported by traditional sectors such as agriculture, manufacturing, mining, fisheries, and forestry. While aquaculture provides economic opportunity in many different places, rural and coastal communities have unique potential to benefit from the expansion of aquaculture.

This goal focuses on delivery of tools that address societal understanding of aquaculture, provide science-based information for regulatory decision-making, improve understanding of the economic aspects of aquaculture businesses, create the specialized workforce needed to develop a robust aquaculture industry, and ensure that the growth of the aquaculture industry is consistent with social values and environmental law. Additionally, new tools are needed to assist with the quantification and valuation of the benefits to the environment that can be attributed to aquaculture. For example, algae and shellfish can mitigate local ecological damage associated with high anthropogenic nutrient loading and acidification of freshwater and near-shore marine systems. Using strong science-based tools and balanced approaches to develop aquaculture will lead to new economic opportunities for Americans across the Nation. New approaches must consider and value the interdependence of sustainability and economic growth and ensure equity by proactively removing barriers for groups historically limited in opportunities to benefit from public investments.

[1] Photos courtesy of the ARS Image Gallery. https://www.ars.usda.gov/oc/images/image-gallery/

[2] Rural America includes the majority (72 percent) of the Nation's land and is home to 46 million people. US Department of Agriculture. *Report to the President of the United States from the Rask Force on Agriculture and Rural Prosperity* (2017). https://www.usda.gov/sites/default/files/documents/rural-prosperity-report.pdf

Objective 1.1: Identify market opportunities for U.S. aquaculture products

USDA Animal and Plant Health Inspection Service Veterinary Services

Partnered with Virginia Tech to conduct an economic analysis of the United States farmed Atlantic Salmon and farmed Rainbow Trout Industries.

Partnered with University of Kansas to conduct an evaluation of the U.S. shrimp farming industry – A Survey-Based Assessment.

USDA Agricultural Research Service

Partnered with Virginia Tech University to assess historic supply of warmwater marine finfish in southern tier states and implications for aquaculture commercialization. https://www.pubs.ext.vt.edu/content/pubs_ext_vt_edu/en/AAEC/aaec-305/aaec-305.html.

USDA National Institute of Food and Agriculture

2023-38504-41022: Expanding New Approaches to Farm Financial Benchmarking; University of Minnesota

2023-67023-39732: Labor Demand, Supply, And Associated Constraints Under Alternative Production Methods In The Bivalve Shellfish Culture Industry; Virginia Institute of Marine Science

RACSRAC-10: Targeted Marketing Research and Outreach for Improving the Position of Southern Aquaculture Products in the Grocery Marketplace; Mississippi State University

RACNCRAC-1: Addressing Critical Aquaculture-Marketing-Oriented Applied Research and Outreach (Phase 2); Purdue University

RACNCRAC-4: Developing Social License for Trout Aquaculture in the North Central Region. Virginia Polytechnic and State University.

RACCTSA-8: Next Steps in Culture of Native Hawaiian Macroalgae: Scale-up and Market Analysis; University of Hawaii

USDA Economics Research Service

Results from a USDA Strategic Priority Grant focusing on the Aquaculture Industry were presented in four seminars given at the Agricultural & Applied Economics Association (**AAEA**) **2023** Annual Meeting in Washington, D.C., July 23- 25, **2023** at the Marriott Marquis hotel.

2023 Aquaculture Track Session:
Seminar 1: **Structure of Industry and Trends in U.S. Aquaculture Industries**
Dr. Ganesh Kumar, Mississippi State University, gkk27@msstate.edu and Dr. Jeffrey M. Gillespie, USDA-ERS, Jeffrey.Gillespie@USDA.gov

Seminar 3: **Trade Potential within U.S. Aquaculture Industries**
Diana Amaya (damaya@agcenter.lsu.edu) and Dr. Lynn Kennedy, Louisiana State University, LKennedy@agcenter.lsu.edu and Dr. Christopher G. Davis, USDA-ERS, Christopher.Davis2@usda.gov

Seminar 4: **Factors Affecting U.S. Consumer Demand for Fish and Seafood**
Dr. Chen Zhen, University of Georgia, czhen@uga.edu and Dr. Abigail Okrent, USDA-ERS, Abigail.Okrent@usda.gov

NOAA Sea Grant
Via the FY23 competition "Aquaculture Economics and Markets Collaborative," established the project entitled "Partnership to advance and enhance aquaculture economics and marketing research and Extension," which seeks to strengthen collaboration between researchers, Extension specialists, and industry in addressing economics and market aspects of US aquaculture.
Via FY23 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing aquaculture market-related projects:

- Maine Oyster Trail: 2022-23 Aquaculture Supplemental Funding
- Strengthening the connections between Wisconsin food fish producers and consumers

Via the FY23 competition "Aquaculture Workforce Technologies and Education Travel Grants Projects," the following projects were established with aquaculture market components:

- Culinary exchange in support of the scallop farming industry in Maine and the northeast US
- Improving Aquaculture Literacy from Great Lakes to Great Seas
- Primary processing bottlenecks: addressing barriers for small to medium-scale seaweed production in the United States

NOAA National Marine Fisheries Service
U.S. marine aquaculture is diverse, not only in the number of species being cultured and production methods, but also in the market environments for aquaculture products in different regions. NMFS seeks to support work that identifies, develops, or expands market opportunities for established as well as less-developed marine aquaculture species nationwide through the following grant program and other support:

FY23 Saltonstall-Kennedy grant program:

- Exploring mutually-beneficial production and marketing strategies for emerging wild and aquaculture quahog industries in Maine
- Pathway to market development: Establishing kelp purchasing cycle best practices
- Expanding cultivated oyster mariculture in Texas
- Diversifying Northern New England's seaweed industry by integrating nori into sugar kelp farming equipment and practices
- A Seafood Equity Hub: addressing barriers to seafood in low-income communities using domestic production and supply chains
- Increasing local seafood consumption in New York through cooking demonstrations and tasting events

Supported NMFS regional science centers with funding for the following projects:

- Measuring social acceptance for US aquaculture
- Understanding the far-field impacts of offshore pen culture on fish and fishermen in the Gulf of Mexico

National Science Foundation

Award # 2306135, NSF Engines Development Award: Advancing climate technologies in Eastern North Carolina, Kenneth Halanych, University of North Carolina at Wilmington, 05/15/2023 – 04/30/2025, TIP Directorate, Innovation and Technology Ecosystems (ITE)

Objective: Use-inspired solutions that promote coastal community resilience will be developed. The project aims to use living ecosystems and their processes to create and enhance products and services. The focal sectors slated for rapid development are coastal infrastructure, aquaculture, and renewable energy targeting five aspects: 1) Engineering with Nature, 2) Environmental Sensing & Signaling, 3) Ecosystem-Inspired Materials, 4) Ecosystem Genetic Engineering, and 5) Ecosystem Service Measuring & Modeling. The project is led by a diverse and responsive team of researchers from universities and community colleges in partnership with Chambers of Commerce, non-profit entities, and for-profit businesses that seek to develop a pipeline for translating use-inspired innovations into marketable products while developing a robust regional workforce.

Objective 1.2: Enable science-based regulation and management of domestic aquaculture

USDA Economics Research Service

Results from a USDA Strategic Priority Grant focusing on the Aquaculture Industry were presented in four seminars given at the Agricultural & Applied Economics Association (**AAEA**) **2023** Annual Meeting in Washington, D.C., July 23- 25, **2023** at the Marriott Marquis hotel.

2023 Aquaculture Track Session:
Seminar 2: **Regulations Guiding the U.S. Aquaculture Industries**
Dr. Jonathan Van Senten, Virginia Polytechnic Institute and State University, jvansenten@vt.edu; Dr. Carole Engel, Virginia Polytechnic Institute and State University, carolee6@vt.edu; and Dr. Aaron Hrozencik, USDA-ERS, Aaron.Hrozencik@usda.gov

US Geological Survey

Stocking fish in inland waters: Opportunities and risks for sustainable food systems. Stocking is one of the foremost tools in the inland fisheries management toolbox, but it comes with both opportunities and risks. Stocking is often used as compensation for depleted wild populations, particularly where recruitment processes have been disrupted, but it can introduce disease, disrupt community structures, reduce genetic integrity, and cause conflicts between fishery stakeholders. Despite its widespread use, examples of effective stocking for food fisheries in inland waters are sparse in the peer-reviewed literature. Nevertheless, it is well established that stocking is frequently used to maintain fish yield, so there is a need to conduct the practice in a robust manner that minimizes the potential risks. This review is the lead paper for a special section of Fisheries Management and Ecology focused on fresh waters feeding the world, which resulted from two panel sessions, one focused on aquaculture and one focused on stocking, The paper highlights current practices of fish stock enhancement in inland waters for food, examines potential synergies and interactions of stock enhancement programs with aquaculture, and provides an outline framework for responsible management of fish stock enhancement. 10.1111/fme.12656

The patchwork governance of ecologically available water. Institutional authority and responsibility for allocating water to ecosystems “ecologically available water” is spread across local, state, and federal agencies, which operate under a range of statutes, mandates, and planning processes. We use a case study of the Upper Missouri Headwaters Basin in southwestern Montana, United States, to illustrate this fragmented institutional landscape. Our goals are to (a) describe the patchwork of agencies and institutional actors whose intersecting authorities and actions influence the ecologically available water in the study basin; (b) describe the range of governance mechanisms these agencies use, including laws, policies, administrative programs, and planning processes; and (c) assess the extent to which the collective governance regime creates gaps in responsibility. We find the water governance regime includes a range of nested mechanisms that in various ways facilitate or hinder the governance of ecologically available water. 10.1111/1752-1688.13167

US Fish and Wildlife Service

FWS contributions in the last year center around expanding both our salmonid import program and our national pathogen surveillance program. Following last year's successful efforts to streamline the T50 import application process via website improvements, the FWS successfully expanded the pool of certifying officials by three, and even added certifying officials in two new countries, New Zealand and Australia. Additionally the Service worked with federal partners to apply the updated National Wild Fish Health Survey geospatial mapper data in support of aquaculture, specifically using data from the National Wild Fish Health Survey to support partner efforts aimed at national freedom from select pathogens.

In 2022 the Service reported that it was using appropriations from the Bipartisan Infrastructure Law to develop an action plan to mitigate the risks of aquatic invasive species (AIS) in trade and transport through commerce (Aquatic Invasive Species In Commerce). The goal of the action plan is to identify regulatory gaps, provide language to assist States in implementing AIS legislation, and develop an online toolkit for industry sellers on restricted species and best management practices. Anticipated completion of the project is September 2024. In 2023, Conservation Collaborations, LLC – the grantees developing the action plan – made significant progress, including:

- Convening a series of seven work groups centered on key issues associated with AIS in commerce to develop specific strategies to address the highest priority issues and gaps that contribute to aquatic invasive species in commerce.
- Developing informational web pages for the seven work groups.
- Holding two summits to review and finalize key terminology, review case studies associated with regulatory issues associated with AIS in Commerce and review draft AIS in Commerce Action Plan that includes strategies and actions to minimize the risks posed by aquatic plants and animals in commerce.
- Developing a first draft of the Action Plan.
- Forming an Advisory Committee to provide guidance and perspectives on project outcomes.
- Holding a focus group meeting at the end of October 2023, to discuss challenges associated with AIS in Commerce and identify the highest priority strategies within each thematic area of the action plan.

NOAA Sea Grant

Via the FY23 competition "Aquaculture Technologies and Education Travel Grants Projects," the following projects were established with regulation/policy components:

- Training and educating auditors, extension agents and regulators on the Regional Shellfish Seed Biosecurity Program
- Great Lakes Aquaculture Decision-Maker Days

Via FY23 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing aquaculture market-related projects:

- Planning for AK mariculture development
- Law and policy fellow – MD Sea Grant
- Support of Eat Wisconsin Fish" and "Great Lakes Fish Finder" websites

NOAA National Marine Fisheries Service

NMFS seeks to support efficient decision-making in regulations and management of a sustainable U.S. marine aquaculture industry based on the best available science. NMFS supports research projects that identify and address key science needs through the following grant programs and other support:

FY23 Small Business Innovation Research Phase I grant program:

- Seaweed-based bioplastic replacement for commercial lobster fishing gear

FY23 Saltonstall-Kennedy grant program:

- Sustainable seaweed farming: Producing reliable, timely and cost-effective kelp seed while reducing reliance and impacts on wild populations
- Toward resolving wild sea scallop larval spatial and temporal distribution along the Maine coast in support of developing scallop aquaculture
- Understanding pathogen dynamics in shellfish nurseries as a basis for expanding the Regional Shellfish Seed Biosecurity Program to nursery settings

Supported NMFS regional science centers with funding for the following projects:

- Support of Oregon/Washington Aquaculture Regulatory Assistance
- Escape risk assessments using the OMEGA model for Aquaculture Opportunity Area Programmatic Environmental Impacts Statements and project specific NEPA reviews, and regional analyses to streamline escape risk considerations
- Quality and valuation of habitat-related ecosystem services provided by oyster aquaculture gear, and development of tools for management
- Integrating ropeless gear technology for inshore and offshore bivalve shellfish aquaculture to maximize economic value while minimizing the potential for adverse effects on marine mammals and sea turtles
- Understanding habitat provisioning by oyster aquaculture - an eDNA metabarcoding approach

National Science Foundation

NSF Engines Development Award: Advancing climate resilient food technologies

Award # 2305455, NSF Engines Development Award: Advancing climate resilient food technologies, Erik Franklin, University of Hawaii, 05/15/2023 – 04/30/2025, TIP Directorate, Innovation and Technology Ecosystems (IT)

Objective: This award is focused on catalyzing an ecosystem for translational research that increases sustainable food production and economic expansion in Hawaii's aquaculture, fisheries, and agriculture sectors. The team will engage with a collective of 18 Minority Serving Institutions that serve Native Hawaiians, Asian Americans, and Pacific Islanders to identify existing programs, fill current gaps in the education landscape, train a skilled labor force, and launch future waves of entrepreneurs for long-term growth in food production.

Award # 2022921 + 2022885, Belmont Forum Collaborative Research: PolyCone Project - An Integrated Approach for Sustainable Pathways of Marine Resources: Cone Snails in French Polynesia, Alexander Dale Mawyer, University of Hawaii + Thomas Duda, University of Michigan Ann Arbor, 02/15/2021 – 01/30/2025, Directorate for Geosciences, Research, Innovation, Synergies, and Education (RISE)

Objective: The project focuses on developing a model to sustainably culture and harvest cone snails. Toxins of cone snails are an important source of pharmaceuticals for treating human health and may have other significant molecular properties with diverse applications. This project will focus on French Polynesia and seeks to provide critical information to help communities develop integrated, ethical, and sustainable harvesting and aquaculture practices. The project will develop a model for the maintenance and enhancement of the sustainable wellbeing of these communities and their linked marine environments and ecologies through an integrated approach to developing new blue economics including significant advances in its aquaculture and venom exploitation processes.

Objective 1.3: Educate and train a skilled, diverse, and inclusive aquaculture workforce

USDA Animal and Plant Health Inspection Service Veterinary Services

Cooperative agreement with the Virginia Institute for Marine Science (VIMS) for veterinary education and training for the molluscan shellfish industry to enhance veterinary expertise in critical aspects of shellfish aquaculture production systems, and for the broader purpose of improving shellfish aquaculture health management in the context of national and international commerce.

Cooperative agreement with Texas A&M for web-based education and training modules targeting aquaculture veterinarians and farmers on topics such as sampling healthy populations of aquatic animal species to demonstrate health status, conducting on-farm risk evaluations for pathways of risk introduction for aquatic animal pathogens of concern, evaluate biosecurity practices and diagnostic test interpretations.

USDA Agricultural Research Service

ARS aquaculture scientists mentored 9 students/post docs, served in 7 adjunct appointments at universities, served as advisors for 2 students, conducted or participated in 15 outreach events to a total of 345 students, and 11 other outreach events to 576 participants.

Established a cooperative agreement entitled" Tribal Marine Aquaculture Research and Workforce Development" with the Jamestown S'klallam Tribe having the Objectives of optimizing management strategies to meet the nutritional requirements of sablefish throughout aquaculture production and provide workforce training opportunities for conducting on-farm shellfish and finish research.

USDA National Institute of Food and Agriculture

2023-70440-40154: Building a pipeline for training and recruiting Indigenous students in coastal resilience and seafood safety; Northwest Indian College

2023-49400-40868: BFRDP GoFarm Hawaii: Growing Hawaii's Agricultural Industry; The University of Hawaii

2023-70017-41375: Aquaponics Bootcamp: An innovative training process to enhance new aqua-farmer success in Appalachia; The Ohio State University

2023-67037-41120: AgriScience Technology Pathways (ATP); The University of Idaho

2023-49400-40891: Growing Alaskan Farmers: An agricultural training program for Alaska Native people and their communities; Calypso Farm and Ecology Center

2023-70440-40175: Agritourism: Regenerative Workforce Initiative for African American and Insular Communities; Northern Marianas College

2023-70440-40176: Bergen Community College New Jersey NexTGen for Sustainable Farming; Bergen Community College

2023-68018-41017: Activating Aquaculture Technology Learning Through Hands-On and Virtual Experiences; University of Maine

2023-77040-41195: Preparing Hispanic and other Underrepresented Students in Fisheries and Aquaculture; The University of Arizona

2023-38821-40369: Providing Experiential Learning Opportunities and Extension training in Aquaculture and Fisheries to Under-served and Underrepresented Student Communities From 1890 Land Grant Institutions.; The University of Arkansas at Pine Bluff

2023-67037-41123: Food & Agriculture & Marine (FAME) 4-H Tech Program; Rutgers, The State University.

RACNRAC-1: Rebooting the Northeast Aquaculture Extension Network: A Skills Training and Mentorship Program for Extension Professionals; University of Connecticut

US Fish and Wildlife Service

The FWS National Conservation Training Center leads the nation with training and education for natural resources managers and provides opportunities for Federal and non-Federal partners. In FY23, there were 5 course offerings in fish health and fish aquaculture. These courses reached over 100 participants, with ~60% of those participants from outside of the FWS. One offering of 'Coldwater Fish Culture' was requested by the Northwest Indian Fisheries Commission and all 36 participants were Tribal members or staff at Tribal Hatcheries in the Pacific Northwest. These offerings highlight the FWS commitment to a diverse and inclusive aquaculture workforce.

The FWS is a leading agency in training for States, Tribes, Federal agencies, and private industry in aquatic animal health management. The Service's Fish Health Centers have hosted undergraduate and graduate students from universities, conducted outreach events, and trained staff from aquaculture facilities across the nation. The staff at each of the Service's Fish Health Centers are leaders in aquatic animal health, provide national leadership in the area of aquatic animal health diagnostics, and help to develop and test methods to diagnose aquatic animal pathogens.

NOAA Sea Grant

Via the FY23 competition "Aquaculture Workforce Development Support Projects," established the following projects:

- Enhancing and Promoting Aquaculture Workforce Development in Hawaii and the Pacific
- Expanding the New Jersey Apprenticeship in Shellfish Aquaculture Program (ASAP)
- Connecticut Aquaculture Workforce Development Strategy
- Extending and Integrating Aquaculture Workforce Development Between Communities
- Developing a Commercial Seafood Workforce Training Program in South Carolina
- Tide's Out: Shellfish Crew and Manager Training
- Designing and launching a community college aquaculture workforce development program to help ready Southern California for a growing aquaculture industry

Via the FY23 competition "Aquaculture Technologies and Education Travel Grants Projects," the following project was established:

- Expansion of the Pier to Peer program for oyster (Crassostrea virginica) aquaculture farmers in the southeastern U.S.

Via FY23 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing workforce development/training projects:

- Aquaculture education and professional development coordinator – MDSG
- The Commercial Oyster Aquaculture Sector Training (COAST) Program, a workforce development initiative aimed at recruiting workers to the oyster aquaculture industry and providing them with training to meet industry demand
- Development of water quality testing training materials for aquaculture producers as well as science teachers
- Support of the Alaska Mariculture Research and Training Center.

NOAA National Marine Fisheries Service

The growing U.S. marine aquaculture industry employs a wide variety of production systems and methods where there is an increasing need for a workforce with unique technical skills and knowledge. NMFS recognizes and is committed to developing a diverse and inclusive workforce to address this need by supporting the following projects and grant programs:

The Aquaculture Information Exchange (AIE) online community platform website was launched in 2023. The AIE represents a joint effort between NOAA's National Sea Grant Office, NOAA's Fisheries Office of Aquaculture, USDA's Agricultural Research Service (ARS), USDA's National Institute of Food and Agriculture (NIFA), and Virginia Sea Grant. The AIE is an online community involving individuals from both the public and private sectors with interests in U.S. aquaculture and related topics. The AIE will serve as a communications platform, actively being moderated to facilitate discussions about current issues facing the industry, the latest research and developments in aquaculture, and will serve as a space where users from across the nation can connect with other members of the aquaculture community.

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

- Empowering coastal Alaska by building local capacity for kelp farming and evaluating best practices for harvesting seed stock

FY23 Saltonstall-Kennedy grant program:

- Refining Aquaculture Methods for Kumu and Establishing Preliminary Tag and Recapture Efforts Utilizing Hawaii's Fishing Community
- Community-based queen conch (*Aliger gigas*) aquaculture in Puerto Rico for restoration and sustainable seafood
- Feasibility analysis for artisanal native oyster mariculture supply chain in Culebra, Puerto Rico

Supported the following projects focused on diversity, equity, and inclusion in aquaculture, including training and building a more diverse workforce:

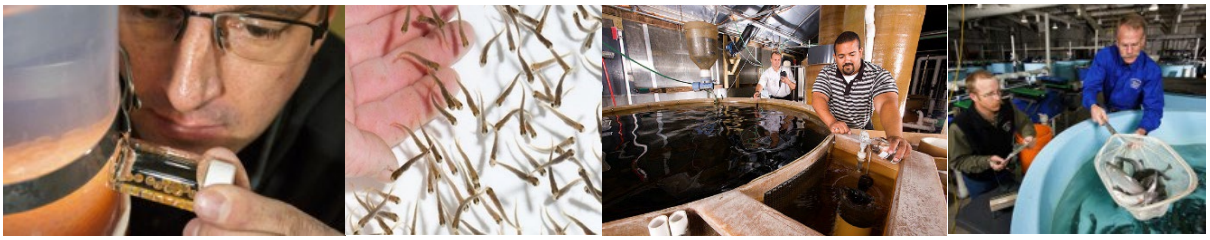
- Providing students from diverse backgrounds opportunities in aquaculture through IN FISH
- Veterinary aquaculture research and policy externship

- Gullah Geechee citizen science approach to monitoring aquaculture farms and preserving tradition
- Tribal partnerships and student aquaculture opportunities in Washington state
- Expanding the network and pipeline for diversity and inclusion in aquaculture
- Minorities in Aquaculture Internship Program 2023
- Interweaving culture and curriculum: Alaska native perspectives on seaweed in the classroom

National Science Foundation

Award # 2231195, TEA Centers: Kiai Loko Center for Limu (algae) Research, Ardis Eschenberg, University of Hawaii, 04/01/2023 – 03/31/2028, Tribal College & University Program Enterprise Advancement Centers

Objective: The Kiai Loko Center for Limu Research partners Windward Community College with non-profit STEM organizations and local knowledge keepers in two major goals: 1) advancing cross disciplinary knowledge of aquaculture and limu (algae) ecology in support of community needs; and 2) training the next generation of Native Hawaiian STEM professionals knowledgeable in these realms. Aquacultural practices employed in the maintenance of healthy fishponds and the production of limu are important aspects of traditional Native Hawaiian lifestyles that contribute to critical contemporary issues such as food security, biodiversity, and cultural perpetuation. The Center partners with community members, Native Hawaiian cultural experts, and STEM professionals in engaging 120 Native Hawaiian high school students in culturally relevant STEM courses, student internships, and the completion of STEM certificates that prepare students for positions as aquaculture technicians for entry into the STEM workforce or the pursuit of higher STEM education.



Goal 2. Improve Aquaculture Production Technologies and Inform Decision-making[3]

Current aquaculture technologies and management tools provide the foundation for further innovation in seafood production, marine resource management, and economic development. However, continual improvements are needed to expand aquaculture consistent with society's increasing need for seafood produced locally under our strict environmental and food safety laws, and to improve the competitiveness of the U.S. industry. The biological sciences and engineering fields converge at a critical juncture of the organism, the culture system, and the environment. Therefore, optimizing aquaculture production requires matching the biology of the species with a production system they can thrive in with minimal impacts on the external environment. For example, a species like rainbow trout must be raised in cool, clear water raceway systems while catfish are raised in warm water pond culture. Furthermore, it is critical that strategies are developed for aquaculture that mitigate the impacts of climate change, including technologies that facilitate adaptation to ocean acidification. Federal science programs serve industry development by 1) focusing on pre-commercial and transitional development of technology to improve production efficiency, product quality, and profitability; and 2) addressing potential environmental and social costs of production by developing tools for informed and objective decision-making at multiple levels of government.

[3]Photos courtesy of the ARS Image Gallery. https://www.ars.usda.gov/oc/images/image-gallery/

Objective 2.1: Provide farmers with access to improved genetics

USDA Agricultural Research Service

Selecting for increased growth and carcass yield and disease resistance in the Delta Select line of channel catfish. ARS researchers in Stoneville, Mississippi, developed the Delta Select line channel catfish with superior growth and carcass yield, and industry has responded favorably to the performance of this new line, which was released in 2020 has been favorable. However, more information was needed about how selecting for growth and carcass yield affected other important performance traits in the Delta Select line. ARS researchers in Stoneville, Mississippi, and Mississippi State University researchers compared how feed conversion efficiency and resistance to two important bacterial catfish pathogens (*Edwardsiella ictaluri* and *Edwardsiella piscicidia*) varied between Delta Select line catfish and randomly selected catfish. The Delta Select line catfish grew faster than the Delta Control line, but both lines demonstrated similar feed conversion efficiencies, indicating the faster growth of the Delta Selects was due to greater feed consumption. In experimental challenges the Delta Control and Delta Select line survived *E. ictaluri* challenge similarly, but the Delta Select had higher survival rates after *E. piscicidia* challenge. The results suggest selection for increased growth and carcass yield in Delta Select line channel catfish has not had a negative impact on feed conversion efficiency or resistance to *E. ictaluri* and may have improved resistance to *E. piscicidia*. This information supports the continued use of the Delta Selects line in the U.S. catfish industry.

Reference genomes for channel and blue catfish. Channel and blue catfish are native to North America and are key to United States aquaculture. Efficiently implementing genomic selection in these species requires accurate, complete genome assemblies. ARS researchers in Stoneville, Mississippi, and collaborators utilized state-of-the-art molecular technologies and bioinformatics to produce highly complete DNA sequence assemblies that accurately represent the channel and blue catfish genomes. The new channel catfish genome assembly is a marked improvement over the previous reference assembly, while the blue catfish genome assembly is new. The researchers identified three chromosomes with large structural changes that likely contribute to lowered fertility observed in channel x blue hybrid F1 offspring. The research also revealed sets of genes that are unique within each species and genes that are unique to both species but different from other fish. The new genome assemblies serve as the reference genomes for these species in the GenBank database and will support genomic selection and selective breeding in both species that will improve U.S. catfish production.

Hybridizing winter and summer spawning lines of trout yields fall spawning broodstock. Rainbow trout lines have been bred and selected to spawn at four different times of the year, necessitating the maintenance and selective breeding of each population to provide year-round egg production of genetically improved eggs. Rainbow trout females will not release their eggs in captivity, requiring hatchery staff to anesthetize and handle female fish once a week to squeeze the abdomen and determine whether eggs have ovulated and can be collected through manual expression. A spawning season with a 3-month window is manageable, but longer spawning seasons (more than 3 months) require more handling events, which can be stressful for fish and is labor intensive for hatchery staff. ARS researchers in Leetown, West Virginia, discovered summer-spawning females that are fertilized with frozen sperm from winter-spawning males produce eggs that yield females. These females, in turn, spawn within a manageable 3-month window in the fall, instead of over a 6 to 12-month window. This hybridization option eliminates the need to maintain and select using a fall-breeding population and

suggests hatcheries with a single population can efficiently extend their egg production season with cryopreserved sperm obtained from males with an alternate spawn time.

High fillet yield trait persists across different commercial diets. There is considerable variation in how much fat is found in commercial rainbow trout diets. Some producers desire a lean diet (16-20 percent fat) while others feed a diet containing up to 35 percent fat. ARS scientists in Leetown, West Virginia, used selective breeding to produce a line of rainbow trout exhibiting high fillet yield (ARS-FY-H), but it is unknown if this trait persists across the range of fat levels commonly found in commercial feeds. The scientists compared how diets with three different fat levels affected growth performance, fillet yield, and fillet quality in the ARS-FY-H line and a low fillet yield line (ARS-FY-L). Both lines exhibited similar growth patterns, but the improved fillet yield trait persisted in the high yield line, regardless of dietary fat content, indicating that trout farmers can continue feeding their preferred dietary fat levels without losing the high fillet yield trait. Additionally, the high yield line exhibited a slightly firmer fillet, suggesting that selection for fillet yield does not compromise fillet quality.

Thermal protocol developed to create triploid hybrid striped bass. ARS researchers in Stuttgart, Arkansas, and Auburn, Alabama, collaborated with an industry partner on developing a protocol to produce triploid hybrid striped bass. Triploidy typically induces sterility, which producers regard as desirable because mature hybrid striped bass will otherwise divert energy from growth to fertility in the production cycle. In small-scale pilot trials, the researchers applied temperature shocks on freshly fertilized eggs and identified the best cold and warm combination to create triploid hybrid striped bass. They used these protocols in the full-scale, commercial production of larvae grown in fish in ponds for 30 days. Results demonstrated that warm temperature shock was better than cold shock to induce a greater percentage of triploid hybrid striped bass and these pond trials demonstrate the potential for producing triploid hybrid striped bass in aquaculture.

Selective breeding of Nile tilapia for resistance to francisellosis does not impact other important commercial traits. *Francisella orientalis* is an important tilapia pathogen that causes francisellosis and results in substantial economic losses for the global tilapia industry. ARS researchers in Auburn, Alabama, and collaborators from Bergen, Norway, and Miami, Florida, assessed options for selectively breeding tilapia with resistance to *F. orientalis* and how this might affect other traits of economic importance. They found fish bred with increasing resistance to *F. orientalis* had high survival rates and did not find unfavorable genetic correlations between commercial traits such as resistance to other pathogens and growth. The results demonstrate that resistance to francisellosis in tilapia can be improved through selective breeding and this strategy will not impact other important commercial traits. This research has led to the development of a robust strain of tilapia that are resistant to disease and exhibit fast growth, important traits for the tilapia industry.

USDA National Institute of Food and Agriculture

2023-70007-40203: Rethinking Selective Breeding For Health: Reduced Pathogen Shedding As A Novel Component of Multi-Trait Enhancement In Salmonid Aquaculture; Virginia Institute of Marine Science

2023-33522-40408: Optimizing Hormone Therapy to Increase Spawning in Single and Redundantly Sterilized Gene-Edited Transgenic Catfish; Auburn University

2023-67016-39339: Just Keep Gilling: Dietary and genetic strategies to improve hypoxia tolerance in rainbow trout; University of Alabama at Birmingham

2023-67015-39742: Integrated genomics and metagenomics predictions and modulation of the gut microbiota-muscle axis to improve fillet yield in rainbow trout; University of Maryland

2023-33530-39340: Evaluation of field performance of hybrid Pacific oysters from crossbreeding; Pacific Hybreed, Inc.

2023-67015-39565: Decoding the Salmonid Genome Project: A national resource for the large-scale functional characterization of genomic elements using gene edited rainbow trout; Washington State University

US Geological Survey

New genomic resource to enable genetic surveys across the native range of brook trout. Recently developed molecular tools make genetic surveys based on standardized single-nucleotide polymorphism (SNP) panels more feasible than ever but require existing genomic information. This paper conducts the first survey of genome-wide SNPs across the native range of brook trout (*Salvelinus fontinalis*), a cold-adapted species that has been the focus of considerable conservation and management effort across eastern North America. The study performed restriction site-associated DNA sequencing for wild brook trout from 82 locations spanning much of the native range and domestic brook trout from 24 hatchery strains used in stocking efforts. The dataset captures a wide spectrum of genetic diversity in native brook trout, offering a valuable resource for developing SNP panels. The study highlights potential applications of this resource with the goal of increasing the integration of genomic information into decision-making for brook trout and other species of conservation or management concern. https://doi.org/10.1111/1755-0998.13853

Genetic population assignments of Atlantic sturgeon. Atlantic sturgeon were once abundant and supported large-scale fisheries throughout much of the east coast of the United States. However, historic overharvest and habitat loss resulted in dramatic declines in abundance and eventual listing under the Endangered Species Act of the United States. As part of this listing, Atlantic sturgeon populations were divided into five distinct population segments (DPSs). However, because subadult and adult Atlantic sturgeon can make large, coast-wide migrations and often mix extensively with individuals from other populations, individuals may be exposed to conservation threats away from their natal river or DPS, ultimately making it difficult to determine the appropriate spatial scale for management activities. To help address this uncertainty, the U.S. Geological Survey performed genetic assignment tests to determine the natal origin of 329 Atlantic sturgeon that were encountered as mortalities or taken during permitted activities in 2021. https://doi.org/10.3133/ofr20231054

NOAA National Marine Fisheries Service

The availability of seed with improved genetics for a variety of commercially-important traits is a powerful tool in supporting a robust and economically viable U.S. marine aquaculture industry. NMFS seeks to provide farmers with access to improved genetics through the following projects and grant programs:

The NMFS Office of Aquaculture continued to support the ongoing collaboration between the NMFS Northeast Fisheries Science Center (NEFSC) and USDA/ARS in the establishment of a Northeast Oyster Breeding Center (NOBC). In this partnership, NMFS NEFSC contributes vital resources such as facilities, administration, scientists and staff support, and coordination with USDA/ARS and the East Coast Shellfish Growers Association. The NOBC hatchery will execute annual breeding plans in partnership with USDA/ARS scientists. This encompasses facilitating oyster seed distribution and growout trials with industry partners. The hatchery will actively engage in collaborative research endeavors with all stakeholders, developing superior oyster lines tailored for deployment by commercial oyster growers in the northeast region. The overarching objective of this initiative is to cultivate eastern oysters capable of thriving in the diverse coastal environments spanning from New York to Maine.

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

- Development of oyster larval cryopreservation technology for commercial seed production

FY23 Small Business Innovation Research Phase I grant program -

- Family-based breeding for production of higher-yielding Manila clam seed
- Sustainable seed production for North Atlantic kelp aquaculture

FY23 Saltonstall-Kennedy grant program -

- Sustainable seaweed farming: Producing reliable, timely and cost-effective kelp seed while reducing reliance and impacts on wild populations

Supported NMFS regional science centers with funding for the following project:

- Refinement of methods for monosex production and sterilization of sablefish

Objective 2.2: Develop and refine production technologies to increase environmentally responsible food production and contribute ecosystem services

USDA Agricultural Research Service

Effect of rotenone on catfish ponds. Rotenone is a naturally occurring compound used to rid ponds of undesirable and/or hold-over fish in catfish ponds before restocking, but previous research in natural water systems showed the recovery of phytoplankton and zooplankton communities could take months, or even years, following rotenone treatment. ARS researchers in Stoneville, Mississippi, and Mississippi State University collaborators evaluated how rotenone use affected various aspects of catfish pond environments. Rotenone treatment did not affect water quality or macroinvertebrate communities, and phytoplankton and zooplankton populations recovered within 14 days after application, nearly the same timeframe as the typical wait time for normal management operations. These findings demonstrate that rotenone has no significant long-term effects on key catfish pond ecology. The research was highlighted in the Fish Culture Section of the American Fisheries Society Winter/Spring 2023 newsletter.

Snail trap prototype. Two species of aquatic snails serve as intermediate hosts for the trematode parasite *Bolbophorus damnificus,* which can infect pond-cultured catfish. Management strategies for the parasite are severely limited, and snail control is the best option for catfish farmers. However, copper sulfate pond treatments to control snails are largely arbitrary because they rely on the farmer's estimate of snail density in each pond. ARS researchers in Stoneville, Mississippi, and Mississippi State University collaborators developed a simple, low-cost snail trap prototype. The prototype used readily available materials, including a cricket cage, PVC pipe, and zip ties. The trap can be deployed into individual ponds to rapidly assess snail populations, enabling farmers to make more informed management decisions in their efforts to control *B. damnificus* host snails.

The role of dietary geosmin in creating 'muddy' off-flavors in fish. The naturally occurring chemical geosmin is responsible for "muddy" or "earthy" off-flavors in fish and is a major quality issue for fish producers across the aquaculture industry. To date, nearly all off-flavor mitigation research has focused on geosmin accumulation in the water. ARS researchers in New Orleans, Louisiana, demonstrated that geosmin from feed can accumulate in fish fillets. By spiking feed with geosmin, researchers established a new method to impart the off-flavor compound into the edible portions of fish. Now ARS scientists can use dietary exposure to study off-flavor prevention and correction in catfish and other species, as well studying the effects of geosmin on sensory quality.

Water quality and waste production during Atlantic salmon depuration. Microbial biofilms can accumulate over surfaces within a recirculating aquaculture system (RAS). The bacteria within these biofilms can produce and release off-flavor compounds that can be taken up by fish and impart objectionable flavors to fillets, thus requiring fish depuration. This is done by holding fish in a separate, biofilm-free system before harvest to eliminate off-flavor compounds from flesh. Although feed is typically withheld while fish are in depuration systems, the fish still add waste (feces and urine) into the system. Best management practices for depurating fish are still being developed in the RAS industry, as water quality and waste production during the depuration process have not been investigated. Extramural ARS scientists in Shepherdstown, West Virginia, performed the first comprehensive analysis of water quality and waste production in an Atlantic salmon depuration system and determined that waste control in depuration systems fully stocked with Atlantic salmon is required for good product

quality. A range of practical recommendations and procedural refinements were determined to optimize depuration system performance. These include 1) extending the depuration period, 2) identifying the optimal location for adding depuration system water to RAS to mitigate solids and ammonia contribution, 3) integrating an internal solids removal process within the depuration system design, and 4) managing dissolved oxygen in depuration systems. These novel management strategies are central to optimizing the removal of off-flavor compounds and improving product quality of fish produced in RAS, thus contributing to industry sustainability through better tasting fish.

USDA National Institute of Food and Agriculture

2023-33610-40789: Novel Manufactured Aquaponic/Hydroponic Raft Design to Address Food Safety Deficiencies and Plant Growth Opportunities; Hawaii Fish Company, Inc.

2023-38821-39957: Sustainability of Integrated Multi-Trophic Aquaculture in Missouri; Lincoln University

2023-70007-40204: Increasing potential of the Yellow Perch industry using new larvae culture technology and enhancing marketability in the Great Lakes region; The Ohio State University

2023-67016-39787: Examining temporal shifts in green sea urchin reproduction which could impact production.; University of Rhode Island

2023-70007-40200: Development of a Rapid, Non-invasive, and Low Cost DNA-based Method for Sex Determination in Russian Sturgeon; North Carolina State University

2023-33530-39342: Developing Tools and Protocols to Establish Freshwater Cod (Burbot; Lota lota) as a New Commercial Aquaculture Species in the US.; Evergreen Aquatics

2023-70019-39366: Development and validation of Sustainable Aquaponics Model Systems to enhance resiliency of Urban, Indoor, and Emerging food systems; The Ohio State University

2023-39410-40790: Inland production of oyster seed utilizing an artificial seawater closed recirculating aquaculture system; Triple N Oyster Farm, LLC.

2023-67016-40777: Development of intensive indoor rearing strategies for largemouth bass during critical early life history stages; Auburn University

2023-33530-39343: Production of largemouth bass for the food fish market using commercial split-pond systems; American Sportfish Hatchery Management Group, LLC.

2023-67016-39786: Increasing Colonization of Stem Cells and Early Detection of Xenogenesis in Catfish with Long Term Reproductive Performance; Auburn University

2023-67023-40297: SEED: Exploring novel fish cultures for small and midscale aquaponics systems; Texas State University

2023-70007-40202: Scalable Strategies to Enhance Sustainable Red Seaweed Aquaculture in Land-Based Cultivation Systems; Oregon State University

2023-70007-40205: An In-situ Biosensor for Rapid Sex Determination: A Critical Tool for Economic Growth and Profitability of Sturgeon Caviar Production; Mote Marine Laboratory, Inc.

RACSRAC-1: Optimizing Production Systems for Removal of Ammonia; USDA ARSWARU

RACSRAC-2: Managing Larval Feeding for Improved Survival by Reduction of Artemia Use and Replacement with Fortified Rotifers or Artificial Feeds; Texas A&M University

RACSRAC-3: Evaluation of Bird Depredation of Traditional and Non-Traditional Species on Aquaculture Farms; Auburn University

RACNRAC-6: Improving Lumpfish Breeding and Spawning; USDA ARS NCWMA

RACNRAC-7: Tautog (*Tautoga onitis*) Early Life Stage Optimization in Recirculating Aquaculture Systems: Spawning, Culture Density, Diet and Behavior Through Metamorphosis; Ward Aquafarms, LLC.

RACNCRAC-5: Genetically Improved All-Female Walleye for Intensive Aquaculture Production in the Great Lakes Region; The Ohio State University

RACCTSA-1: Development of a Sustainable Aquaculture and Fishery for the Mangrove Crab *Scylla serrata* Forskall; Palau Community College

RACCTSA-2: Developing Bivalve Farming in Hawaii; University of Hawaii

RACCTSA-3: Demonstration Aquaponics Unit for Formerly Homeless Village; University of Hawaii

RACCTSA-4: Pilot Scale Hatchery Production and Fishpond Grow-out of Hawaiian Sea Cucumbers; Pacific American Foundation

RACCTSA-5: Improving Forktail Rabbitfish (*Siganus argenteus*) Production in the CNMI and the Micronesian Region; Northern Marianas College

RACCTSA-6: Design of a Harvesting System for the Marine Polychaete, *Marphysa sanguinea* (Phase 1); Oceanic Institute of Hawaii Pacific University

RACCTSA-7: Herbivorous Reef Fish *Kyphosus vaigiensis*: Fishpond and Commercial Potential; University of Hawaii

US Geological Survey

Is chemical control for crayfish in hatchery fish shipments practical? Invasive crayfish displace native crayfish species and alter aquatic habitat, community structure, and ecosystem function. A new publication evaluated whether chemical control can be a reliable control agent for crayfish to ensure that shipments from fish hatcheries did not result in new infestations of invasive crayfish. A series of

acute (≤1 h) toxicity tests were conducted to evaluate the toxicity of cypermethrin and pyrethrin to crayfish, freshwater mussels, and fish; chemical concentrations in test organisms; effectiveness of carbon-block filters to remove cypermethrin from test waters; and the cost of chemical control relative to extra handling of fish. For all other fish tested, chemical control was 4–10 times more expensive than extra handling. Special use permits or chemical registration are needed before chemical control for crayfish could be routinely used at fish hatcheries. 10.1002/naaq.10291

US Fish and Wildlife Service

In addition to the applied research contributions listed below, the FWS is an international leader in the development and application of technologies related to conservation aquaculture which contributes directly to ecosystem services, and even food sources via harvest fisheries. Currently, a major environmental challenge rests with rapidly changing rearing conditions and conservation needs. Resilience to a changing climate is a technology development priority in this field and the FWS is actively assessing and adapting to associated operational challenges. The Service has conducted climate change vulnerability assessments for several National Fish Hatcheries and has plans to implement this practice more broadly. In response to the findings of these assessments, facilities have adopted novel aquaculture technologies to mitigate the impacts of decreased flows and warmer water, altered operations to avoid subjecting sensitive life stages to acute summer conditions, and increased preparedness for extreme weather events.

In addition, FWS published multiple articles in the last year related to improving hatchery production and conservation outcomes to support valuable fisheries and ecosystems.

Relevant 2023 FWS Research Publications

Bioretention filtration prevents acute mortality and reduces chronic toxicity for early life stage coho salmon (*Oncorhynchus kisutch*) episodically exposed to urban stormwater runoff. As the human population of western North America continues to expand, widespread patterns of urban growth pose increasingly existential threats to certain wild stocks of Pacific salmon and steelhead (*Oncorhynchus* spp.). Rainfall previously absorbed into the soils of forests and grasslands falls instead on pavement and other hardened surfaces. This creates stormwater runoff that carries toxic metals, oil, and many other contaminants into salmon bearing habitats. These include freshwater streams where coho salmon (*O. kisutch*) spawn in gravel beds. Coho salmon embryos develop within a thick eggshell (chorion) for weeks to months before hatching as alevins and ultimately emerging from the gravel as fry. Untreated urban runoff is highly toxic to older coho salmon (freshwater-resident juveniles and adult spawners), but the vulnerability of the earliest life stages remains poorly understood. To address this uncertainty, we fertilized eggs and raised them under an episodic stormwater exposure regimen, using runoff collected from a high-traffic arterial roadway from 15 discrete storm events. We monitored survival and morphological development, as well as molecular markers for contaminant exposure and cardiovascular stress. We also evaluated the benefit of treating runoff with green infrastructure (bioretention filtration) on coho salmon health and survival. Untreated runoff caused subtle sublethal toxicity in pre-hatch embryos with no mortality, followed by high rates of mortality from exposure at hatch. Bioretention filtration removed most measured contaminants (bacteria, dissolved metals, and polycyclic aromatic hydrocarbons), and the treated effluent was considerably less toxic - notably preventing mortality at the alevin stage. Our findings indicate that untreated urban runoff poses an important threat to early life stage coho salmon, in terms of both acute and delayed-in-time mortality. Moreover, while inexpensive management strategies involving bio-infiltration are promising, future

green infrastructure effectiveness research should emphasize sublethal metrics for contaminant exposure and adverse health outcomes in salmonids. http://dx.doi.org/10.1016/j.scitotenv.2023.165759

No effect of stocking density on the survival or size of late-stage delta smelt larvae reared in a small-scale culture system. Objective: A small-scale culture system effective in producing larvae of endangered delta smelt, *Hypomesus transpacificus,* was recently developed to facilitate conservation and research efforts. Methods: To optimize its use, we examined the effect of stocking density (300, 500, 700, and 900 fish per 92 L of water) on the length, weight, and survival of late-stage larvae (41 days posthatch) reared for 40 days in the small-scale system. Result: Stocking density had no effect on larval survival or size. Also, the survival, length, and weight of these fish did not differ from those reared using standard, large-scale culture practices (2500 fish per 320 L of water). Conclusion: Our findings validate the methods used for small-scale delta smelt rearing, help optimize these protocols, and thereby enhance delta smelt rearing capabilities needed for research and conservation. This study optimizes and validates use of a new culture system for rearing a specific life stage of delta smelt. In doing so, we enhance ongoing conservation efforts to prevent the extinction of this endangered species. http://dx.doi.org/10.1002/naaq.10303

The optimal stocking strategy for Yaqui catfish. Objective: The Yaqui catfish, *Ictalurus pricei*, a species that is endemic to the southwestern United States and west-central Chihuahua and Sonora, Mexico, is extinct in the United States and extremely endangered in Mexico due to habitat loss and hybridization with nonnative channel catfish, *I. punctatus*. To re-establish populations in the United States, a binational program consisting of broodstock collection, fish propagation, stocking, and post-stocking monitoring is necessary. This programmatic approach is encapsulated within a Conservation Propagation and Stocking Program (CPSP), which documents important recovery actions, such as genetic management, fish culture, stocking, and post-stocking assessments. The focus of our work is to identify the optimal stocking strategy for Yaqui catfish, thereby informing the framework of a CPSP for the species' recovery. Methods: Our strategy involved simulating population growth using an age-structured simulation model with varying stocking contribution rates, stocking densities, and stocking frequencies and incorporating these biological data with economic information within a utility function to quantify stocking costs. Result: The optimal strategy requires releasing Yaqui catfish at a density of 200 fish/ha every 5 years. This strategy excludes natural recruitment because historically, stocked Yaqui catfish inhabited waters that were either too small or devoid of habitat to induce natural spawning. However, if larger waters or waters having appropriate habitats (e.g., interstitial spaces) are also stocked, it should increase natural recruitment, thereby (1) enabling populations to become self-sustaining and (2) drastically reducing the reliance on hatcheries for stocking and salvage of declining populations. Conclusion: Our results provide important stocking recommendations within a CPSP, emphasizing the need to build a broodstock before genetically pure Yaqui catfish disappear. The successful implementation of the optimal stocking strategy requires multiple locations for stocking fish and is contingent on strengthening binational partnerships. This approach fills an important void in Yaqui catfish reestablishment, helping to prime the successful recovery of this species. The Yaqui catfish, once native to regions of the United States and Mexico, faces near extinction due to habitat degradation and nonnative hybridization. A binational Conservation Propagation and Stocking Program offers a promising solution, suggesting for the release of 200 fish per hectare every 5 years in the United States. The initiatives success, however, hinges on using multiple stocking locations in Mexico and bolstering binational collaboration. http://dx.doi.org/10.1002/nafm.10942

Morphological differences between wild and hatchery-reared bloater (*Coregonus hoyi*) from Lake Michigan, USA. Coregonines (ciscoes and whitefishes) are economically, ecologically, and culturally important fishes that are distributed throughout the Northern Hemisphere. In the Laurentian Great Lakes, coregonines declined throughout the 19th and 20th centuries, and managers have prioritized their restoration. A key restoration tool is reintroduction via stocking. However, hatchery-reared coregonines can display different morphologies than wild fish, which could affect their fitness. Unfortunately, our understanding of these differences is limited because previous work did not adequately remove allometric effects in morphological analyses. We compared morphologies between wild and hatchery-reared bloater (*Coregonus hoyi*) from the same stock using appropriate size corrections. Hatchery-reared fish had shorter heads, shorter dorsal fins, and shallower bodies than wild fish. Moreover, some characters differed across wild fish collections. Our results improve our understanding of how artificial rearing can impact coregonine morphology, and we recommend future studies on what causes these differences and whether they impact fitness. http://dx.doi.org/10.1111/fme.12653

Captive-reared delta smelt (*Hypomesus transpacificus*) exhibit high survival in natural conditions using in situ enclosures. Conservation of endangered fishes commonly includes captive breeding, applied research, and management. Since 1996, a captive breeding program has existed for the federally threatened and California endangered delta smelt *Hypomesus transpacificus*, an osmerid fish endemic to the upper San Francisco Estuary. Although this program serves as a captive refuge population, with experimental releases being initiated to supplement the wild population, it was uncertain how individuals would survive, feed, and maintain condition outside hatchery conditions. We evaluated this and the effects of three enclosure designs (41% open, 63% open, and 63% open with partial outer mesh wrap) on growth, survival, and feeding efficacy of cultured delta smelt at two locations (Sacramento River near Rio Vista, CA and in Sacramento River Deepwater Ship Channel) in the wild. Enclosures exposed fish to semi-natural conditions (ambient environmental fluctuations and wild food resources) but prevented escape and predation. After four weeks, survival was high for all enclosure types (94-100%) at both locations. The change in condition and weight was variable between sites, increasing at the first location but decreasing at the second location. Gut content analysis showed that fish consumed wild zooplankton that came into the enclosures. Cumulatively, results show that captive-reared delta smelt can survive and forage successfully when housed in enclosures under semi-natural conditions in the wild. When comparing enclosure types, we observed no significant difference in fish weight changes ($p = 0.58$-0.81 across sites). The success of housing captive-reared delta smelt in enclosures in the wild provides preliminary evidence that these fish may be suitable to supplement the wild population in the San Francisco Estuary. Furthermore, these enclosures are a new tool to test the efficacy of habitat management actions or to acclimate fish to wild conditions as a soft release strategy for recently initiated supplementation efforts. http://dx.doi.org/10.1371/journal.pone.0286027

Hatchery supplementation increases potential spawning stock of Rio Grande silvery minnow after population bottlenecks. Objective: Supplementation of imperiled wild fish stocks with captively raised fish is a commonly used conservation tool. Programs designed to maintain or improve fish populations through supplementation should be evaluated to determine whether they are meeting conservation objectives. The Rio Grande silvery minnow, *Hybognathus amarus,* is a small-bodied, endangered minnow endemic to the Rio Grande basin of the southwestern United States. The wild population of Rio Grande silvery minnow has been supplemented with captive-reared fish since 2002.

Our objective was to determine whether supplementation measurably increases the number of spawning fish after years of population bottlenecks; this objective was simplified because nearly all hatchery-released fish have been given identifying markings. Methods: We leveraged a long-term fish sampling data set (18 years) covering the species' contemporary range and a single-season, high spatial coverage fish sampling data set to determine whether the number of potential spawners was increased by the addition of hatchery fish. Result: Hatchery-reared fish increased the catch rates of spawners by up to an order of magnitude in some years. We also observed that most hatchery-reared fish were recaptured near the point of release. We were able to determine that supplementation with hatchery fish increased the abundance and distribution of Rio Grande silvery minnow and provided the desired demographic boost after severe population bottlenecks. Conclusion: Releasing hatchery-reared fish may be a useful tool for conservation of imperiled freshwater fishes. However, there is a need for spawning and rearing infrastructure that matches the life-history of the species and sufficient post release monitoring to evaluate the effectiveness of hatchery supplementation. Use of hatchery-reared fish has been beneficial for improving population resiliency of Rio Grande silvery minnow following recruitment bottlenecks; however, natural recruitment can greatly exceed hatchery supplementation and conditions promoting natural recruitment should be restored. http://dx.doi.org/10.1002/tafs.10398

Parentage Analysis Reveals Unequal Family Sizes during Hatchery Production. Lake sturgeon (*Acipenser fulvescens)* is a species of conservation concern that has been stocked in several Great Lakes (North America) rivers. Lake sturgeon were extirpated in the Ontonagon River in Lake Superior and stocking began in 1998. In 2017, gametes were collected from spawning lake sturgeon (9 females, 36 males) caught at the nearby Sturgeon River spawning ground, generating nine family groups using a 1:4 mating design (n = 862). In 2018, gametes were collected from 3 females and 15 males, generating three family groups, and additional collections of drifting fry from the Sturgeon River were reared in the hatchery, resulting in 84 hatchery-produced and 675 wild-caught fry for stocking in the Ontonagon River. The objective of this study was to compare paternal representation and genetic diversity between the two stocking strategies. Parentage analysis based on genetic data from 12 microsatellite loci determined none of the family groups in the hatchery had equal paternal representation ($p < 0.001$), while wild-produced offspring had equal paternal representation. Despite the larger number of breeders contributing to the wild-caught larvae, there was no significant difference in genetic diversity between the wild-caught larvae and representative hatchery-produced offspring. http://dx.doi.org/10.3390/fishes8030140

Fecundity trends of Chinook salmon in the Pacific Northwest. Fecundity is an important demographic parameter that contributes to the productivity of anadromous fish stock dynamics. Yet, studies on fecundity patterns in Pacific salmon (*Onchorhynchus* spp.) often only include a few years of data, limiting our ability to understand spatio-temporal trends. Here, we used data on 43 hatchery Chinook salmon (*O. tshawytscha, Salmonidae)* populations in Washington State to evaluate whether average fecundity changed over the past three decades. We then used data from a subset of stocks (18) to evaluate the relationship between fecundity and body length. Our results revealed significant changes in fecundity across the 25-year study period with most stocks showing declines in fecundity over the past decade. Results further showed that Chinook salmon have decreased in length over this same period and that annual variation in mean length explains a majority (62%) of annual variation in mean fecundity. Specifically, we estimated that a 1-mm reduction in length results in 7.8 fewer eggs (95% CI = 6.6-8.9). Given that the majority of Pacific Northwest Chinook salmon in the environment and

harvested in fisheries originate from hatchery releases and that nearby hatchery and wild populations generally have similar ocean distributions, these results likely reflect patterns for many populations not included. Combined, our results highlight the need to consider changes in body size and egg production when assessing the dynamics of anadromous fish populations and designing management or conservation plans, particularly for depressed populations. http://dx.doi.org/10.1111/faf.12738

Retention of passive integrated transponder tags in hatchery brook trout: Effect of tag size, implantation site, and double tagging. A fundamental assumption of mark-recapture studies is that individuals do not lose their marks or tags, because tag loss can lead to biased parameter estimates. Retention of 8-mm full-duplex and 12-mm half-duplex passive integrated transponder (PIT) tags implanted in the abdomen, opercular musculature, and dorsal sinus of age-0+ hatchery male brook trout (*Salvelinus fontinalis*) was evaluated in the laboratory. Treatments included single- and double-tagged fish. Survival, growth, and tag retention were monitored for 181-187 days for 640 tagged fish and 80 untagged controls. Survival to 180 days ranged 95%-100% and was not affected by tagging. PIT-tagging caused a short-term reduction in growth rates. Tag retention to 180 days was 100% for dorsal implantation, 83.0% with 8-mm tags in the operculum, 97.5% with 8-mm tags in the abdomen, and 99.6% with 12-mm tags in the abdomen. Retention of opercular tags was positively related to size at tagging. Tag loss was independent of whether fish were single- or double-tagged. Double tagging with one full- and one half-duplex PIT tag in different body locations would hedge against data loss relative to single tagging, especially for longer-lived and iteroparous species where tag loss through time is more likely. http://dx.doi.org/10.1111/fme.12616

Does hatchery rearing of lake trout affect their reproductive behavior in the wild? Stocking of hatchery-reared fishes has been used with variable success as a management action to promote the recovery of populations and species. The practice has been controversial for several reasons, including uncertainty about whether the hatchery rearing experience may affect reproduction after release. Fine-scale acoustic telemetry was used during three spawning seasons to test whether hatchery rearing affects the reproductive behavior of lake trout using a spawning shoal complex in northern Lake Huron. Within sex, wild-and hatchery-reared fish behaved similarly, but significant behavioral differences occurred between sexes. Lake trout of both sexes moved synchronously onto the spawning shoals at the completion of autumn thermal turnover and occupied the same spawning sites (confirmed visually by presence of fertilized eggs) on the shoals. Male lake trout tended to congregate directly on spawning sites, with duration of occupancy varying greatly among years. Female lake trout spent less time on spawning shoals than males and congregated less at spawning sites on shoals. Most fish visited multiple spawning sites among shoals per season, with many making multiple transits among individual spawning sites. We found no evidence to support the hypothesis that hatchery rearing impairs spawning behavior of lake trout and, therefore, conclude that behavior deficiencies on the spawning ground are likely not an impediment to rehabilitation of lake trout in northern Lake Huron. Our study narrows the field of possible impediments to lake trout rehabilitation in the Great Lakes and provides insights that expand the conceptual model of lake trout spawning behavior. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/ licenses/by-nc-nd/4.0/). http://dx.doi.org/10.1016/j.jglr.2022.11.002

17β-Estradiol Can Induce Sex Reversal in brown trout. Hormones have been used to change phenotypic sex in many fish species. However, information specific to changing sex in brown trout (*Salmo trutta*) is lacking. This study compared the effectiveness of two different 17 beta-estradiol (estradiol) concentrations (20 mg/kg and 30 mg/kg) fed to brown trout for 60 days, beginning at initial feeding. At 456 days post-initial feeding, the 20 mg/kg and 30 mg/kg treatment groups were 84% and 86% female, respectively. These values were significantly higher than the 47% females observed in the control group which did not receive dietary estradiol. At the end of the 60-day estradiol treatment period, weight gain, percent weight gain, and feed conversion ratio were all significantly lower in the tanks of fish receiving estradiol than in the control tanks. Individual fish fed estradiol also weighed significantly less and were significantly shorter than the fish not receiving estradiol-coated feed. Mortality ranged from 1.0 to 2.4% among the treatments and was not significantly different. After 105 days post-initial feeding, weight gain, percent weight gain, and feed conversion ratio were not significantly different among the treatments. At 456 days post-initial feeding, individual fish were significantly longer and heavier in the 20 mg/kg estradiol treatment compared to the fish in the control treatment, and the fish in the 30 mg/kg estradiol treatment were similar to the other two treatments. This study is the first to document the successful sex reversal of brown trout using estradiol. While the estradiol treatments used in this study did not lead to complete feminization, the observed 85-to-15% female-to-male phenotypic ratio indicates the successful feminization of genetic males. The levels of feminization observed in this study are suitable for this initial step to potentially develop a YY male broodstock to control invasive brown trout populations. This study was for research purposes only and has not been evaluated by the FDA.
http://dx.doi.org/10.3390/fishes8020103

Validation of a microwave energy meter to non-lethally estimate energetic reserves in adult sturgeon. Whole-body (WB) energetic reserves influence fish survival, growth, and reproduction but are typically quantified using lethal methods (i.e., proximate analyses) or interpreted through body condition indices. Energetic reserves can impact population dynamics through influences on growth rates, age-at-first-reproductive-maturity, and spawning periodicity at the individual-fish level, especially in long-lived sturgeon species. Therefore, a non-lethal tool to track the energetic reserves of endangered sturgeon populations could inform adaptive management and further our understanding of the sturgeon's biology. The Distell Fatmeter is a microwave energy meter that has been validated to non-lethally estimate energetic reserves in some fish species, but never successfully for sturgeon. Here, stepwise linear regressions were applied to test commonly monitored body metrics and Fatmeter measurements at nine different anatomical sites on captive adult pallid sturgeon (*Scaphirhynchus albus*; total length of 790-1015 mm; WB lipid of 13.9-33.3%) compared with WB lipid and energy content determined by proximate analyses. Fatmeter measurements alone explained approximately 70% of the variation in WB energetic reserves, which outperformed models considering body metrics alone by a margin of approximately 20%. The top-ranked models based on AICc score (second order Akaike Information Criterion) included a combination of body metrics and Fatmeter measurements and accounted for up to 76% of the variation in WB lipid and energy. We recommend the incorporation of Fatmeter measurements at a single site located dorsally to the lateral scutes at the posterior end of the fish above the pelvic fins (U-P) into conservation monitoring programs for adult pallid sturgeon (total length [TL] >= 790 mm; fork length [FL] >= 715 mm) and the cautious application of Fatmeter measurements for sturgeon between 435 and 790 mm TL (375-715 mm FL). Measurements at this U-P site combined with body mass explained approximately 75% of the variation in WB lipid and energy. We successfully validated the Fatmeter as a tool to obtain precise, non-lethal estimates of whole-body

energetic reserves in captive adult pallid sturgeon. The study provides recommendations for the implementation of Fatmeter measurements in monitoring programs for free-living sturgeon and include measurement sites and formulae to estimate whole-body lipid and energy using raw measurements. http://dx.doi.org/10.1093/conphys/coad023

Effects of turbidity, temperature, and predation cue on the stress response of juvenile delta smelt. The San Francisco Estuary (SFE) is one of the most degraded ecosystems in the United States, and organisms that inhabit it are exposed to a suite of environmental stressors. The delta smelt (*Hypomesus transpacificus*), a small semi-anadromous fish endemic to the SFE and considered an indicator species, is close to extinction in the wild. The goal of this study was to investigate how environmental alterations to the SFE, such as reductions in turbidities, higher temperatures and increased prevalence of invasive predators affect the physiology and stress response of juvenile delta smelt. Juvenile delta smelt were exposed to two temperatures (17 and 21 & DEG;C) and two turbidities (1-2 and 10-11 NTU) for 2 weeks. After the first week of exposure, delta smelt were exposed to a largemouth bass (*Micropterus salmoides*) predator cue at the same time every day for 7 days. Fish were measured and sampled on the first (acute) and final (chronic) day of exposures to predator cues and later analyzed for whole-body cortisol, glucose, lactate, and protein. Length and mass measurements were used to calculate condition factor of fish in each treatment. Turbidity had the greatest effect on juvenile delta smelt and resulted in reduced cortisol, increased glucose and lactate, and greater condition factor. Elevated temperatures reduced available energy in delta smelt, indicated by lower glucose and total protein, whereas predator cue exposure had negligible effects on their stress response. This is the first study to show reduced cortisol in juvenile delta smelt held in turbid conditions and adds to the growing data that suggest this species performs best in moderate temperatures and turbidities. Multi-stressor experiments are necessary to understand the capacity of delta smelt to respond to the multivariate and dynamic changes in their natural environment, and results from this study should be considered for management-based conservation efforts. http://dx.doi.org/10.1093/conphys/coad036

Reproductive cycles of alligator snapping turtles (*Macrochelys temminckii*). The alligator snapping turtle (*Macrochelys temminckii*) is a species for which captive propagation and reintroduction programs are well established; however, little is known about its reproductive behavior and physiology. In this study, we measured monthly plasma sex steroid hormone concentrations of androgen (T + DHT) estradiol-17B (E2), and progesterone (P4), and used ultrasonography to monitor annual reproductive cycles of a captive population of alligator snapping turtles that is maintained under semi-natural conditions in southeastern Oklahoma. Concurrently, we used automated radio telemetry to measure the relative activity levels of male and female alligator snapping turtles and examine these activity patterns in the context of their reproductive cycles. We also measured monthly concentrations of the glucocorticoid (GC) corticosterone (CORT). Seasonal variation was only detected for T in males, but was observed for T, E2, and P4 in females. Vitellogenesis began in August and ended in April and coincided with elevated E2. Ovulation took place 10-29 April and the nesting period lasted from 11 May - 3 June. Males exhibited greater relative activity levels than females in the fall, winter, and early spring, which coincided with the period when mature sperm would be available for mating. Females were more active than males during the peri-nesting period in the spring. Seasonal changes in CORT were detected and did not differ between males and females. CORT concentrations were elevated in the late spring and summer, coincident with the foraging season, and depressed in the fall, and winter, and at their nadir in the early spring. http://dx.doi.org/10.1016/j.ygcen.2023.114310

NOAA Sea Grant

Via FY23 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing aquaculture production related project:

- Land-based IMTA production – PRSG
- Extension support of aquaculture production - GUSG

NOAA National Marine Fisheries Service

Continuous development and refinement of marine aquaculture production systems and methods are critical to enable growth of the U.S. marine aquaculture industry. Exploring and maximizing opportunities for aquaculture to provide ecosystem services is also crucial for development of a sustainable industry. NMFS seeks to support these efforts by funding research projects through the following grant programs:

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

- Functionally balanced and sustainable shrimp feed production by upcycling food wastes for enhancing shrimp aquaculture in the US
- A novel, cost-effective and automated production system combining extensive plankton culture with intensive, commercial-scale larviculture of blue crab, *Callinectes sapidus*
- Encouraging successful recirculating aquaculture and aquaponic systems
- Coculture of native grazers species with established farmed bivalves
- Development of oyster larval cryopreservation technology for commercial seed production
- Optimization of grow-out culture of Caribbean king crab
- Intensive land-based cultivation of macroalgal cultivar, i.e. graceful red weed (*Gracilaria spp*.), in outdoor open tank recirculating aquaculture systems to increase productivity.
- Continued development of innovative hatchery technology for black grouper (*Mycteroperca bonaci*) including integrated multi-trophic aquaculture (IMTA) with oysters (*Crassostrea virginica*) and seaweed (*Asparagopsis taxiformis*).
- Automation of oyster cages for improved farmer profits and productivity
- Development of an integrated multitrophic aquaculture system to increase production and profitability of Hawaiian fishponds
- Development of a pilot-scale hatchery and nursery culture techniques for Pacific calico scallops (*Argopecten ventricosus*) as a new shellfish aquaculture species for California
- Comparing land-based and net-pen culture of Sablefish (*Anoplopoma fimbria*) and assessing an integrated multi-trophic aquaculture (IMTA) approach using giant red sea cucumbers (*Apostichopus californicus*)
- Overcoming hurdles and expanding opportunities for sea cucumber aquaculture in Hawaiian fishponds
- Development of an integrated multitrophic aquaculture system to restore Hawaii's vulnerable limu (seaweed) populations
- Collective grassroots pathways toward restorative aquaculture: Removing invasives and bringing back native species

FY23 Small Business Innovation Research Phase I grant program:

- Seaweed-based bioplastic replacement for commercial lobster fishing gear

FY23 Small Business Innovation Research Phase II grant program:

- Development and evaluation of peroxide free fin-fish nursery feeds with active DHA-synthase enzyme (DSe)
- Sustainable seed production for North Atlantic kelp aquaculture

FY23 Saltonstall-Kennedy grant program:

- Sustainable seaweed farming: Producing reliable, timely and cost-effective kelp seed while reducing reliance and impacts on wild populations
- Development of hatchery technology and juvenile grow-out techniques for warty sea cucumbers
- Refining aquaculture methods for kumu and establishing preliminary tag and recapture efforts utilizing Hawaii's fishing community
- Community-based queen conch (*Aliger gigas*) aquaculture in Puerto Rico for restoration and sustainable seafood
- Toward resolving wild sea scallop (*P. magellanicus*) larval spatial and temporal distribution along the Maine coast in support of developing scallop aquaculture
- Feasibility analysis for artisanal native oyster mariculture supply chain in Culebra, Puerto Rico
- Understanding pathogen dynamics in shellfish nurseries as a basis for expanding the Regional Shellfish Seed Biosecurity Program to nursery settings
- Diversifying Northern New England's seaweed industry by integrating nori into sugar kelp farming equipment and practices
- Development of technologies using black soldier fly larvae to efficiently convert seafood processing wastes into value-added marine feed ingredients
- Expanding cultivated oyster mariculture in Texas

Supported NMFS regional science centers with funding for the following projects:

- Further development of macroalgae feed ingredients for marine fish
- Developing monitoring and mitigation strategies for Harmful Algal Blooms on Alaska oyster farms
- Integrating ropeless gear technology for inshore and offshore bivalve shellfish aquaculture to maximize economic value while minimizing the potential for adverse effects on marine mammals and sea turtles
- Quality and valuation of habitat-related ecosystem services provided by oyster aquaculture gear, and development of tools for management
- Refinement of methods for monosex production and sterilization of sablefish
- Determine which microalgae yield optimal postlarval abalone growth and survival
- A decision tool for sea farmers to balance tradeoffs between growing diploid and triploid Pacific oysters: expanded life-cycle and geographic scope, behavioral response and regional maps
- Flow cytometric analysis of hemocyte immune functions in the Pacific Oyster (*Crassostrea gigas*) in response to in vitro exposure to bacterial probiotic strain OY15: Confirmation of immune stimulation as the mechanism of OY15's beneficial effects on survival, fitness and increased settlement of Pacific oyster larvae seen during hatchery-scale trials
- Understanding habitat provisioning by oyster aquaculture - an eDNA metabarcoding approach

National Science Foundation

Award # 2306173, I-Corps: High Intensity pulsed light for the removal of off-flavor compounds in aquaculture effluents, Osvaldo Sepulveda Villet, University of Wisconsin Milwaukee, 02/01/2023 – 07/31/2024, TIP Directorate, Translational Impacts (TI)

Objective: The project involves the development of a new technology to increase the production of an aquaculture enterprise by reducing fish mortality and producing higher quality farmed fish. It will more effectively remove off-flavor compounds (aromatic byproducts of microbial metabolism) that are concentrated during intensive recirculating aquaculture and during bioaccumulation in the tissues of fishes.

Objective 2.3: Advance fish nutrition and feed production technologies to produce healthy fish, reduce environmental impacts and provide nutritious seafood

USDA Agricultural Research Service

Evaluating the effects of insect meal in fish feeds. The increased demand and reduced supply of fishmeal and fish oil have prompted the search for sustainable alternatives for aquaculture feeds. Insects are part of the natural diet of fish and have a small ecological footprint because they have a limited need for space. ARS researchers in Bozeman, Montana, collaborated with university scientists, trout producers, and insect growers to determine the nutritional value of insects for salmonids. Their study data indicate insects are promising candidates for fish feeds and results provide feed companies with the information necessary to incorporate insect meal into commercial feed formulations. The global insect feed market is valued at $1.2 million and is expected to reach $3 million by 2030. A 2020 report indicated that using insect meal as feed resources in commercial salmonid feeds between 2016 and 2020 grew to low but reportable levels (0.4 percent of the total feed volume) for the first time. These levels are projected to increase, and aquaculture feed markets are projected to become the main market for insect meals by 2030.

Fish feed formulations for improving hatchery discharge water quality. Dietary formulation can greatly impact water quality in fish hatcheries. ARS scientists in Hagerman, Idaho, collaborated with the U.S. Fish and Wildlife Service and University of Idaho and found that ammonia levels in water discharged from rainbow trout production facilities can be significantly reduced by lowering feed protein content from 41 percent to 35 percent. This reduction did not affect growth performance. They also determined that phosphorus (P) bound as phytate-P in plant protein sources, normally unavailable to rainbow trout, could be utilized by rainbow trout after treatment with phytase enzyme. This allowed rainbow trout to obtain physiological requirements for P, negated the need for additional dietary phosphate, and reduced P discharge in effluent. Phytase additions reduced water-soluble P waste loads by 43 percent from the fishmeal-based feeds and 56 percent from the plant-based feeds. Without phytase treatment of plant-based diets, trout growth performance declined and there was a marked increase in P output. Government agency water quality managers are continually reducing allowable limits of P release from production facilities into downstream rivers and streams, and these restrictions can reduce fish production and growth potential. This information is being used by feed manufacturers and producers to meet water quality requirements, which allows aquaculture producers to increase production while reducing phosphorus discharge from their facilities.

Whole wheat grain is a good source of carbohydrates for farm-raised Florida pompano. ARS funded researchers in Fort Pierce, Florida, tested several carbohydrate sources in Florida pompano feeds and found whole wheat grain was the best carbohydrate option for feed formulation. It resulted in better juvenile growth performance and better feed intake and feed efficiency than other sources of carbohydrates. Using whole wheat grain to supplement diets ultimately reduces feed cost and waste ammonia release to the environment without affecting the nutritional balance of feed, which will contribute to the economic sustainability of aquaculture operations.

Using black soldier fly larvae frass in an aquaponic system. Aquaponics integrates aquaculture with hydroponics by using fish waste as plant nutrients, but adding supplemental nutrients to enhance plant production is also common. Frass (insect manure and the substrate used to culture insects) can be used to enhance fish and plant production and, depending upon the culture substrate used to grow the

insects, it may be possible to enhance both plant and fish growth in an aquaponic system using diet. ARS researchers in Auburn, Alabama, and Stuttgart, Arkansas, collaborated with University of Arkansas at Pine Bluff researchers on evaluating channel catfish juveniles raised in an aquaponic system that were fed diets with black soldier fly larvae (BSFL) frass. Each system had floating raft and media beds used to grow stevia and lavender. Catfish grew significantly better when fed a diet with BSFL frass and their intestinal histology exhibited reduced inflammation. Stevia and lavender had significantly more biomass when frass was added to the system, while plants grown in media beds were larger than plants grown in a floating raft subsystem. These results indicate that feeding catfish with BSFL frass and culturing stevia and lavender in media beds can improve overall productivity.

Black soldier fly byproducts in tilapia diets harmful to liver. Black soldier fly farming offers a sustainable opportunity to provide ingredients for livestock feeds, including fish species. One of the byproducts for black soldier fly larvae (BSFL) farming is the exuviae (exoskeleton) that remains after larvae metamorphose to adults. Exuviae is rich in chitin, which might act as a prebiotic in some species of fish. ARS researchers in Stuttgart, Arkansas, and University of Arkansas at Pine Bluff collaborators evaluated how adding various amounts of ground exuviae to tilapia feed affected fish growth, biochemical composition, hepatic expression, and liver/intestinal histomorphology. Dietary BSFL did not affect growth, feeding efficiency, or fatty acid composition, but histological examinations found mild to severe liver changes ranging from localized inflammation to necrosis and hemorrhaging. Results appear to indicate that BSFL exuviae may be harmful to liver health in tilapia, which could limit its use in fish feed.

USDA National Institute of Food and Agriculture

2023-67021-39643: Circular Aquaculture Through A Next-Generation Waste-to-Feed Biotechnology; Auburn University

2023-67022-39645: Automating Black Soldier Fly Rearing For On-Farm Waste Recycling And Income Generation; University of California at Riverside

2023-33530-39423: Commercialization of PDMA (Partially Digested Macroalgae) to decarbonize animal feeds by improved control of macroalgae fermentation processes; Ocean Era, Inc.

2023-67019-39248: Sustainable Insect Farming Contributing To Food, Water And Energy Security; Texas A&M University

2023-33610-40796: Heterologous Synthesis of Polyunsaturated Fatty Acids for Aquaculture; Xylome Corp.

RACSRAC-4: Utilizing Feeding Stimulants and Liquid Diets to Improve Larval Feeding Performance and Minimize the Use of Artemia in the Larval Production of Freshwater and Marine Ornamental Fish Species; The University of Florida

RACNRAC-5: Improving Lumpfish Grow-out Production: Optimizing Feed Strategies; University of New Hampshire

RACNCRAC-2: Asian Carp Muscle as an Initial Dietary Protein Source and Palatability Enhancer for Successful Production of Yellow Perch and Walleye Fingerlings; Southern Illinois University Carbondale

RACWRAC-5: Mixing up an optimal diet for white sturgeon grow-out; USDA ARS Bozeman Fish Technology Center

US Geological Survey

Genetic basis of thiaminase I activity in fish. Consumption of fish containing thiaminase has led to elevated mortality and recruitment failure in farmed animals and wild salmonine populations around the world. In the North American Great Lakes, consumption of the non-native prey fish alewife by native lake trout led to thiamine (vitamin B1) deficiency, elevated fry mortality and impeded natural population recruitment. Several thiaminases have been genetically characterized in bacteria and unicellular eukaryotes, and the source of thiaminase in multicellular organisms has been hypothesized to be gut microflora. This study identified thiaminase I genes in zebrafish with homology to bacterial thiaminase. The biochemical activity of zebrafish thiaminase I was confirmed and genes homologous to the zebrafish thiaminase gene were identified in many animals, including common carp, zebra mussel, and alewife. Thus, the source of thiaminase I in alewife impacting lake trout populations is likely to be de novo synthesis. https://doi.org/10.1038/s41598-023-27612-5

Thiamine supplementation improves survival and body condition of hatchery-reared steelhead. Thiamine (vitamin B1) deficiency causes early mortality in salmonids; however, the thiamine status of Oregon's steelhead populations is unknown. To investigate if thiamine deficiency was causally related to fry survival, scientists from Oregon Fish and Wildlife and USGS injected females with buffered thiamine HCl prior to spawning. Additionally, a subset of eggs were supplemented via bath treatment with thiamine at spawning. Cumulative fry mortality at 8 weeks post-hatch from thiamine-injected females was 2.9% compared to 13.8% mortality of fry without thiamine supplementation. Fry treated only with the thiamine via bath as eggs had a mortality rate of 6.9%. There were no additional improvements for the survival of fry from injected females that also received a thiamine bath. Furthermore, condition factors were greater in thiamine-supplemented fry than in those that received no thiamine. These data identify thiamine deficiency in Oregon steelhead and suggest supplementation with thiamine can mitigate early rearing mortality. 10.3390/vetsci10020156

US Fish and Wildlife Service

The US Fish and Wildlife Service National Fish Hatchery System, consisting of 73 National Fish Hatcheries, 13 Applied Science Centers and the Aquatic Animal Drug Approval Partnership, regularly conducts applied aquaculture nutrition research in support of conservation priorities. This research is broadly disseminated and thus carries the added benefit of advancing aquaculture in general, as exemplified by selected publications listed below:

Performance of phytase-treated fishmeal-free and all-plant protein diets in pond production of market sized hybrid striped bass. We determined if ideal protein (IP), fishmeal-free (FMF), or all-plant protein (PP) diets of available ingredients satisfied production needs of hybrid striped bass (HSB; *Morone chrysops x M. saxatilis*) grown to market size in ponds managed according to industry practices, and if phytase (Phy) superdosing (20,000 FTUs) could alleviate inorganic phosphorus supplementation. An off-the-shelf commercial feed (COM), an IP control diet containing 16% fishmeal (FM), and four IP test diets with or without phytase superdosing (FMF, FMF + Phy, PP, PP + Phy) were evaluated. Inorganic

phosphorus was excluded from phytase treated diets. Hybrid striped bass (averaging 344 g/fish) were stocked (5187 fish/ha) in 4 ponds/diet (0.1 ha) and grown for 5.5 months. Most responses of the five ideal protein diets did not differ significantly (P > 0.1) from the COM. Only net fish yield, weight gain, and FCR of the PP diet were less than those of the COM diet. Fish fed FMF and FMF + Phy diets had higher fish yields, mean weights, and gains than PP and PP + Phy diets. FMF ponds had fewer than expected large (907-1134 g) and more jumbo (>1135 g) fish and FMF + Phy ponds had fewer medium (680-906 g) and more large fish. PP ponds had fewer than expected jumbo fish. The COM diet resulted in larger livers (HSI), lower muscle ratio, but less feed phosphorus added to ponds compared to the FM diet. Absence of differences for other responses confirms the FM diet is a valid proxy for the COM diet. Phytase increased energy and protein retention of the PP diet but not the FMF diet. FM can be replaced with animal and/or plant proteins exclusively without major reductions in hybrid striped bass performance. The PP diet likely requires optimization of Met and branched chain amino acid levels to improve performance. Inorganic phosphorus can be replaced by diet phytase top-coating and judicious inclusion of phytate-phosphorus without negative impact on HSB production. Phytase superdosing of the FMF and PP diets did not improve production variables but did improve mineral retentions, more so for the PP diet. Phytase superdosing reduced feed phosphorus fed by 60% and pond phosphorus loading by 40% but requires optimization of inclusion levels and economic evaluation before recommendation. http://dx.doi.org/10.1016/j.aquaculture.2023.740006

Genome-wide insights into whole gut microbiota of rainbow trout, *Oncorhynchus mykiss,* fed plant proteins and camelina oil at different temperature regimens. Gut microbiota impacts fish metabolism, nutrient utilization, and health. We know little about how temperature and diet interact with rainbow trout gut microbes. A total of 288 fish (average body weight: 45.6 g) fed four iso-caloric, -lipidic, and -nitrogenous diets comprised crude protein (40%) and lipid (20%) manufactured as 100% animal-based protein (AP) and blend of 50 fish oil (FO)/50 camelina oil (CO), 100% AP and 100% CO, 100% plant-based protein (PP) and blend of 50 FO/50 CO or 100% PP and 100% CO at 14 or 18 degrees C water temperature. Gut content was analyzed using 16S rRNA gene and shotgun sequencing. Alpha-diversity did not change significantly. Regardless of diet, Tenericutes, Firmicutes, Proteobacteria, Spirochaetes, Bacteroidetes, and Actinobacteria dominated. At family level, *Aeromonadaceae* and *Enterobacteriaceae* dominated at 18 degrees C, while *Mycoplasmataceae* dominated at 14 degrees C. Moreover, genes relating to amino acid, carbohydrate, fat, and energy metabolisms and fatty acid biosynthesis significantly increased at 18 degrees C. Functional profiles did not vary significantly among diets, except for a higher methionine and cysteine metabolism in fish fed plant ingredient compared animal diet, suggesting trout fed plant-derived protein mixed with CO could be as effective as those fed fish meals mixed with 50/50 FO and CO. http://dx.doi.org/10.1111/jwas.13028

Effects of dietary soybean meal inclusion on calcium-binding protein expression and inflammatory gene markers in liver and intestine of Atlantic salmon (*Salmo salar L.*). Atlantic salmon (*Salmo salar L.*) are sensitive to the inclusion of soybean meal in the diet which can result in inflammation in the distal intestine. Expression of S100 genes have been shown to be upregulated as part of the inflammatory response to antinutritional factors in soybean meal. These genes are also involved in calcium homeostasis in marine teleosts. We examined expression of S100I2 and S100V2 genes coding for calcium-binding proteins in the distal intestine and liver between groups of Atlantic salmon fed a fishmeal (FM) or soybean-meal (PM) diet for 12 weeks. These two genes have been previously shown to differ in binding motifs and share variable sequence identity. Juvenile Atlantic salmon (71.25 & PLUSMN; 0.76 g) were cultured in 140 L tanks using flowthrough freshwater at 15°C and

randomly assigned to FM or PM diet groups in triplicate. Fish were fed daily to satiation and subsampled from each tank every four weeks. Expression of S100I2 in the distal intestine was elevated by 8 weeks but expression did not differ between diets. Expression of S100V2 was significantly elevated in the distal intestine of fish fed the PM diet compared to fish fed the FM diet. Increased expression of S100V2 but not S100I2 at 8 and 12 weeks in fish fed the PM diet differs from observations in previous studies using rainbow trout and implies Atlantic salmon raised in freshwater may regulate expression of S100V2 and S100I2 in their distal intestine differently than rainbow trout. Expression of S100I2 and S100V2 in liver was not different between dietary treatments. Semi-quantitative histological scores confirmed mild but significant distal enteritis in the PM diet group but not in the FM diet group. Overall, these results provide further understanding in the expression of S100 genes and inflammatory processes associated with soy-induced distal enteritis in salmonids. http://dx.doi.org/10.1016/j.aqrep.2023.101624

Evidence of a divided nutritive function in rainbow trout (*Oncorhynchus mykiss*) midgut and hindgut microbiomes by whole shotgun metagenomic approach. The nutritive role and ecology of gut-dwelling microbes in rainbow trout remain enigmatic. To improve our understanding of the rainbow trout gastrointestinal tract (GIT) microbiome, we performed whole shotgun metagenomic analyses on the assembled contigs from luminal contents from both mid- and hind-GIT regions for taxonomic and functional classifications of fish-fed animal and plant protein dietary sources. Our study revealed that trout respond well to the two diets containing animal and plant protein sources when supplemented with essential amino acids to meet the requirements of the fish. Microbes present were predominantly bacteria (89.9%) and mainly of the phyla Tenericutes, Firmicutes, Fusobacteria, and Proteobacteria. Eukaryotic (8.8%) microbes were mainly from phyla Ascomycota and Basidiomycota, while Archaea (<1%) were also present and predominantly from the phylum Euryarchaeota. Comparisons of genus-level classifications and functional profiles revealed compositional differences in these GIT locations that appear modulated by differences in the dietary treatments. The functional analysis provided evidence of amino acid biosynthesis/catabolism and methane production in the mid-GIT, while in the hind-GIT, proteolytic hydrolysis and butyrate metabolism were expressed in the trout fed with plant protein diet. The animal protein-based diet provided metabolites for microbial protein fermentation in the hind-GIT. Our report highlights and identifies the potential nutritive contributions of GIT microbes to trout and a potentially crucial functional division along the GIT. Finally, the plant-based diet enhanced amino acid catabolism in the midgut section, while the hindgut section supports evidence of methanogen fermentation. http://dx.doi.org/10.1016/j.aqrep.2023.101601

Liver Glycogen as a Sensitive Indicator of Food Limitation in delta smelt. Assessing habitat quality is a major goal of conservationists and restoration practitioners, but to associate habitat quality with biomarkers of vagile animals, the biomarkers must respond rapidly. Here, we identified a biomarker capable of rapidly detecting food limitation in the imperiled delta smelt (*Hypomesus transpacificus*), a pelagic fish endemic to the San Francisco Estuary (SFE). We conducted an experiment with fed and unfed treatments of hatchery-raised, sub-adult delta smelt that were sampled at 12 time points: 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 14, and 21 days. We then compared four biomarkers using Day 21 fish: RNA/DNA in liver, triglycerides in liver, glycogen in liver, and glycogen in muscle. Of the liver endpoints, glycogen had the largest difference between treatments at Day 21, so we compared it to muscle glycogen across all time points. Liver glycogen declined by 60% after 1 day of fasting and remained depressed in the fasting treatment across all subsequent time points. Muscle glycogen also responded rapidly, taking only 2 days to decline by 39% in the fasting treatment, but the difference was inconsistent across subsequent time points. When applied to hatchery-released delta smelt collected from the SFE, liver

glycogen concentrations were less than half that of the fed hatchery fish, consistent with the hypothesis of food limitation in the wild, but also several other potential causes. This study highlights the utility of liver glycogen as an indicator of recent foraging success in delta smelt. http://dx.doi.org/10.1007/s12237-023-01282-y

NOAA National Marine Fisheries Service

Feed expenses often constitute a significant portion of the operational costs for certain commercial marine aquaculture operations that rely on external feeding. Furthermore, it is critical that aquaculture feeds be developed to minimize environmental impact and use of limited natural resources. NMFS seeks to support novel solutions to these issues for finfish and other species by funding research projects through the following grant programs:

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

- Functionally balanced and sustainable shrimp feed production by upcycling food wastes for enhancing shrimp aquaculture in the US

FY23 Small Business Innovation Research Phase II grant program:

- Development and evaluation of peroxide free fin-fish nursery feeds with active DHA-synthase enzyme (DSe)

FY23 Saltonstall-Kennedy grant program:

- Development of technologies using black soldier fly larvae to efficiently convert seafood processing wastes into value-added marine feed ingredients

Supported NMFS regional science centers with funding for the following projects:

- Further development of macroalgae feed ingredients for marine fish
- Determine which microalgae yield optimal postlarval abalone growth and survival

Objective 2.4: Improve engineering systems for aquaculture

USDA Agricultural Research Service

Using artificial intelligence to detect fish mortalities. Early detection of elevated mortalities in aquaculture systems is crucial for timely management to prevent mortality escalation. Conventional mortality detection approaches rely on human observation and tracking that is sometimes augmented with underwater cameras. However, this approach can delay responding, especially when personnel are mostly or entirely off-site and might not provide the timely monitoring needed to prevent a significant mortality event. In addition, higher stocking densities and cloudy water can obscure visual observation of mortalities. Extramural ARS scientists in Shepherdstown, West Virginia, developed MortCam, an Artificial Intelligence- and Internet of Things (IoT)-enabled fish mortality detection and alert system that provides 24-hour surveillance for recirculating aquaculture system (RAS) conditions and reliably sends email and text alerts to fish production staff about mortality events. This technology will provide RAS farmers with a critical tool for reliable early-mortality detection and notification, which will support effective and timely treatments to prevent mortality escalation, improve fish welfare, and prevent economic losses.

Optimizing carbon dioxide removal in recirculating aquaculture systems. Fish release dissolved carbon dioxide (CO2), so CO2 levels must be managed in culture tanks to ensure levels are safe for fish. Recirculating aquaculture systems commonly bubble air through the water to remove CO2 but management protocols for optimal performance have yet to be defined. Extramural ARS scientists in Shepherdstown, West Virginia, optimized protocols for removing CO2 in RAS using diffused air as the stripping gas in a relatively shallow water column and characterized how water flow, CO2 water levels, diffused airflow rates, and water depths affected CO2 removal efficiencies. These findings provide RAS farmers with management protocols for effectively removing dissolved CO2 using aeration basins in freshwater RAS, improving water quality, fish health, and production efficiency.

A vacuum degasser reduces gas supersaturation of well water. Most commercial catfish operations in the southeast United States use water that comes from deep aquafers, but this water is often supersaturated with nitrogen gas that is harmful to fish. ARS researchers in Stoneville, Mississippi, used water sources that mimicked commercial conditions to develop a vacuum degasser that eliminates nitrogen supersaturation from well water without changing other water quality parameters and facilitated research on oxygen requirements. This research will help researchers and producers develop best practices for improved water quality for fish production in commercial ponds.

USDA National Institute of Food and Agriculture

2023-33610-40928: LATERAL.systems: Edge Based Indoor Farm Monitoring Platform; Lateral Systems, LLC.

2023-67022-38976: CPS: Medium: Integrating sensors, controls, and ecotoxicology with decoupled aquaponics using brackish groundwater and desalination concentrate for sustainable food production; University of North Texas

2023-51402-39243: Development of a Portable, Biochar-Based Electrochemical PFAS Sensing Device to Protect Rural Water Resources; Cache Environmental Laboratories, P.C.

2023-68016-39718: A Near-zero-emission Aquaculture Production System through Phycoremediation, Anaerobic Digestion, and Emission Mitigation; Purdue University

2023-67021-40625: PARTNERSHIP: Leveraging anaerobic ammonium oxidation for sustainable aquaculture; Virginia Polytechnic Institute and State University

NOAA National Marine Fisheries Service

Developing engineering solutions to optimize system performance, minimize production costs, and reduce environmental impact is critical in developing a viable and sustainable U.S. marine aquaculture industry. NMFS seeks to support research projects that explore such engineering solutions through the following grant program and other support:

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

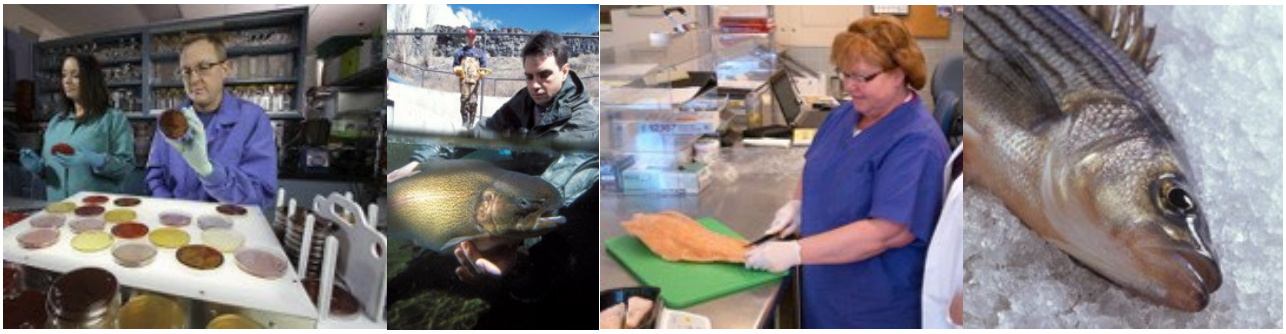
- A novel, cost-effective and automated production system combining extensive plankton culture with intensive, commercial-scale larviculture of blue crab, *Callinectes sapidus*
- Encouraging successful recirculating aquaculture and aquaponic systems

- Intensive land-based cultivation of macroalgal cultivar, i.e. graceful red weed (*Gracilaria spp*.), in outdoor open tank recirculating aquaculture systems to increase productivity
- Continued development of innovative hatchery technology for black grouper (*Mycteroperca bonaci*) including integrated multi-trophic aquaculture (IMTA) with oysters (*Crassostrea virginica*) and seaweed (*Asparagopsis taxiformis*)
- Automation of oyster cages for improved farmer profits and productivity
- Development of an integrated multitrophic aquaculture system to increase production and profitability of Hawaiian fishponds
- Comparing land-based and net-pen culture of sablefish (*Anoplopoma fimbria*) and assessing an integrated multi-trophic aquaculture (IMTA) approach using giant red sea cucumbers (*Apostichopus californicus*)
- Seaweed-based bioplastic replacement for commercial lobster fishing gear

Supported NMFS regional science centers with funding for the following projects -
Integrating ropeless gear technology for inshore and offshore bivalve shellfish aquaculture to maximize economic value while minimizing the potential for adverse effects on marine mammals and sea turtles

National Science Foundation
Award # 2300136 + 2300137, Collaborative Research: Engineering host-associated synthetic consortia based on ecological modules, Otto Cordero Sanchez, MIT, and Salvador Almagro-Moreno, University of Central Florida, 09/01/2023 – 08/31/2027, Directorate for Biological Sciences, MCB and IOS

Objective: Synthetic microbiomes will be constructed to increase feed efficiency in the brine shrimp, *Artemia salina*, and prevent infection by a bacterial pathogen, Vibrio parahaemolyticus, which is responsible for great losses from disease in aquaculture worldwide



Goal 3. Uphold Animal Well-Being, Product Safety, and Nutritional Value[4]

Given seafood's many health benefits, 2020-2025 US Dietary Guidelines for Americans recommends increasing seafood consumption in the United States.[5] Demonstrating the safety and nutritious value of domestic aquaculture products will inform consumer decisions on seafood purchases. Similarly, promoting health benefits could improve food security as higher demand will stimulate more domestic aquaculture production. Access to healthy farmed seafood products starts with healthy aquatic organisms grown in healthy aquatic ecosystems. "One Health"[6] concepts recognize that the health of people is connected to the health of farmed organisms and the environment. *One Health* approaches to developing healthy ecosystems are collaborative, multisectoral, and transdisciplinary—working at the local, regional, national, and global levels—with the goal of achieving optimal health outcomes. These approaches recognize the interconnection between people, animals, plants, and their shared environments.[7] Optimal implementation of *One Health* principles requires the development and coordination of programs, policies, legislation, and research in which multiple sectors communicate and work together to achieve better public health outcomes. Specifically, the concept focuses on ways to improve food security, quality, and safety; control diseases; and manage environmental factors through harmonization and standardization. To apply the *One Health* concept to aquaculture, Federal research should be coordinated to:

- Improve aquatic animal and algal health management;
- Ensure the safety of all biologics and therapeutics being used in domestic aquaculture;
- Promote and ensure the safety and health benefits of consuming aquaculture products;
- Minimize the potential for impacts on the environment from aquaculture facilities;
- Restore endangered species and habitats;
- Increase the socioeconomic health of communities;
- Improve U.S. food and nutritional security; and
- Where appropriate, minimize negative secondary impacts to human, animal, and plant health.

[4] Photos courtesy of the ARS Image Gallery. https://www.ars.usda.gov/oc/images/image-gallery/
[5] The 2020-2025 Dietary Guidelines: https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf (accessed February 14, 2024)
[6] World Health Organization. *One Health* (21 September 2017). https://www.who.int/features/qa/one-health/en/
[7] Centers for Disease Control and Prevention. *One Health.* https://www.cdc.gov/onehealth/index.html

Objective 3.1: Develop strategies to protect the health and well-being of aquaculture species

USDA Animal and Plant Health Inspection Service Veterinary Services

- **Maine infectious salmon anemia (ISA) control program 20 YR Program Review.** Partnership with Maine NOAA Sea Grant to conduct (1) a historical review of ISA Program activities, (2) examine trends in pathogen detection and disease occurrence through time, (3) explore stakeholder input on program objectives and function, and (4) identify Program elements considered key to achieving evolving definitions of Program success.
- **Early Disease Detection Needs Assessment & Mortality Reporting for Shellfish Producers.** Agreement with the Pacific Shellfish Institute to improve the understanding of the industry's needs for early disease detection and shellfish mortality events on the U.S. west coast. This project will help characterize needs and ways forward for enhancing early disease detection systems to protect the health of shellfish and the shellfish aquaculture industry on the Pacific Coast. To do this the Pacific Shellfish Institute (PSI) will work with shellfish producers, diagnostic laboratories, monitoring programs, and agencies on the west coast to 1) support health and disease monitoring, 2) characterize shellfish mortalities, 3) identify shellfish farm health plan needs and assist with plan development, 4) identify producer concerns about geographical mortality reporting, and 5) identify shellfish seed biosecurity and mitigation protocols and needs to prevent introduction and dissemination of pathogens and invasive organisms.
- **Establishment of quality control parameters for antimicrobial susceptibility testing of *Flavobacterium psychrophilum* and *Flavobacterium columnare* by disk diffusion.** Project goal is to improve options and capacity for antimicrobial susceptibility testing (AST) of important bacterial pathogens of aquatic animals and support development of standards for AST for monitoring antimicrobial resistance in aquaculture. The major objectives of this project will be to develop testing protocols and define quality control ranges for AST using *E. coli* and *A. salmonicida*, common reference strains, for a Tier 2 quality control study appropriate for *F.psychrophilum* and *F. columnare*.
- **Risk Assessment of Fish Movements from Great Lakes Region Fish Farms and Hatcheries to Natural Waters or Other Premises During a Viral Hemorrhagic Septicemia Outbreak**. Assessment conducted via agreement with the University of Minnesota (MN03.21).
- **Development of Environmental Models to Advance Aquaculture Disease and Surveillance.** Agreement with University of Kansas.
- **Interagency agreement with USDA ARS National Cold Water Marine Aquaculture Center (NCMA)** to collaboratively investigate and mitigate ISAV HPR0 persistence or entry points at NCMA by surveying all life stages of Atlantic salmon at the hatchery and environmental samples to identify critical control points.
- **Cooperative agreement with University of Arizona, Aquaculture Pathology Laboratory** to identify a real-time assay for the detection of infectious hypodermal and hematopoietic necrosis virus (IHHNV) including test performance characteristics. Dhar, Arun, K, Cruz-Flores, Roberto, Mai, Hung N., Warg, Janet. 2024. Comparison of Polymerase Chain Reaction (PCR) assay performance in detecting *Decapod penstylhamaparvovirus* 1 in penaeid shrimp. Journal of Virological Methods, 323https://doi.org/10.1016/j.jviromet.2023.114840
- **Cooperative agreement with University of Hawaii, College of Tropical Aquaculture and Human Resources** to enhance the ability of the State to provide support to Hawaii's shrimp industry in

response to shortage of testing labs by building surge capacity that utilized high throughput workflow using APHIS VS standardized protocols.

- **Cooperative agreement with University of Florida, Wildlife and Aquatic Veterinary Disease Laboratory** to generate a standardized protocol for a network of testing laboratories to conduct a ring trial to evaluate inter-laboratory performance.
- **Cooperative agreement with University of Maryland/Baltimore County** to enhance the ability to detect OsHV-1 which included evaluation of real-time PCR assay, establishing SOPS for use in export testing laboratories, evaluate archived known infected tissue to increase the number of publicly available OSHV-1 whole genome sequences.
- **Cooperative agreement with Virginia Institute of Marine Science of the College of William Mary** to identify genus and species-specific real-time PCR assays.
- **Cooperative agreement with University of Illinois** to evaluate the efficiency of utilizing oligo baiting to identify pathogens in a primary sample. Case studies will be pathogens causing neurologic disease in horses, and pathogens causing morbidity in fish, crustaceans, and mollusks. Objective is to compare this method to the single plex PCR and determine sensitivity parameters.
- **Grant awarded through the National Animal Health Laboratory Network (NAHLN) to Washington Animal Disease Diagnostic Laboratory at Washington State University.** Grant to develop rapid pathogen detection by unbiased deep sequencing as a diagnostic tool for multiple agent specific assays on single tissue sample.
- **Grant awarded through the National Animal Health Laboratory Network (NAHLN) to Bronson Animal Disease Diagnostic Laboratory in Florida.** Grant to conduct a comparison of published real-time spring viremia of carp virus (SVCV) assays.

USDA Agricultural Research Service

Proliferative gill disease risk assessment model. Proliferative gill disease (PGD) is caused by a ubiquitous myxozoan parasite and causes substantial losses in commercially raised catfish. Most losses occur when catfish fingerlings are moved to grow-out ponds for food fish production. ARS researchers in Stoneville, Mississippi, developed a PGD risk assessment model to determine the likelihood of fish losses in newly stocked production ponds or when fish are understocked for food fish production. The risk assessment model relies on comprehensive water analysis and uses eDNA methodologies and a quantitative polymerase chain reaction (PCR) assay specifically developed and validated through this project. By determining the parasite's infectious life stage levels in the pond water, they established correlations between parasite levels and mortality events observed in experimental pond trials, which enabled them to accurately assess the probability of fish losses upon stocking. This program has been implemented as a demonstration project on farms where water samples are collected concurrently with sentinel fish exposures to identify ponds that can be safely stocked with minimal risk to fish health.

Improved salmon pathogen detection. Infectious salmon anemia virus (ISAV) is a serious viral pathogen of salmon and is internationally regulated based on virus phenotype. Standard phenotypic detection methods require using a molecular assay that takes days to generate results. ARS researchers in Orono, Maine, and University of Maine colleagues developed an improved molecular method that has increased testing speeds five- to ten-fold while maintaining equal if not better accuracy for ISAV detection. This improved assay has been transferred and used by industry stakeholders in a high-pressure, high-volume situation to quickly screen 1,600 broodstock for the presence of the virus and prevented losses of hundreds of thousands of dollars.

Vaccine protection against different strains of Weissella tructae (formerly Weissella ceti). Weissellosis, caused by *W. tructae*, is an economically important emerging disease of farmed rainbow trout that can cause production losses as high as 40-80 percent. Until recently, all strains of *W. tructae* formed a genetically homogeneous group, suggesting a recent emergence of this pathogen. ARS scientists in Leetown, West Virginia, identified a *W. tructae* strain that is genetically distinct from previously characterized strains and likely represents an additional independent emergence of this pathogen. In addition, vaccination experiments established that strong cross-protection is conferred by vaccines prepared from either bacterial strain, indicating that only one strain is needed in the vaccine. This information has been vital to stakeholders for formulating a pre-exposure vaccine to protect against multiple distinct strains of this pathogen.

Water source influences the microbiome at a commercial trout aquaculture facility. Microbiomes can influence development, disease, and overall fish health, but more information is needed about their impact at commercial trout farms. ARS scientists in Leetown, West Virginia, and University of Connecticut partners analyzed 163 microbiome samples collected during 3 years from fish, water, and tank surfaces at a commercial trout production facility. They found that the incoming water microbiome influences the type of microbes associated with fish and tank surfaces and that the fish pathogen *Flavobacterium columnare* was associated with source water and prevalent during disease outbreaks. This study identified a potential source and reservoir of an important pathogen and will lead to improved farm biosecurity and disease control.

USDA National Institute of Food and Agriculture

2023-33530-39561: Field-deployable CRISPR-based diagnostics for improved biosecurity in aquaculture; Sherlock Biosciences Inc.

2023-38821-39968: Functional significance of Rhesus glycoproteins in mitigating toxic ammonia build-up in catfish challenged with elevated environmental ammonia and water borne iron in aquaculture practices; The University of Arkansas at Pine Bluff

2023-33530-39345: Low-cost Diagnostic Platform for Aquaculture; EmergingDx Inc.

2023-70007-40201: Investigation of vaccination and disease susceptibility of largemouth bass fry during the early rearing stages; Auburn University

2023-38424-38747: Using molecular methods to determine the role of phytoplankton in West Coast shellfish die-offs; Northwest Indian College

2023-67015-39481: One-pot RT-LAMP CRISPR/Cas12b platform for rapid detection of tilapia lake virus; The University of Florida

2023-67016-39712: Molecular Mechanisms of Interspecies Interactions In Mitigating Aquaculture Diseases; The University of Rhode Island

2023-67011-40515: Evaluation of a Recombinant *Flavobacterium covae* Vaccine in Conjunction with a Dietary Probiotic in Channel Catfish (*Ictalurus punctatus*); Auburn University

RACSRAC-5: Investigating the Epidemiology of *Edwardsiella piscicida* -Septicemia in Hybrid Catfish and Other Commercially Important Fish Species in the Southern United States; Mississippi State University

RACSRAC-6: Evaluation of Probiotics in Finfish Hatcheries to Improve Larval Production; Texas A&M University

RACSRAC-7: Development of Rapid Detection Methods for Emerging Aquatic Animal Pathogens Threatening Southern Region Aquaculture; Mississippi State University

RACSRAC-8: Identification of novel *Flavobacterium columnare* vaccine candidates for catfish and other aquaculture fish species in the Southern region; Auburn University

RACSRAC-9: Investigating the Emergence of Vibriosis in Catfish Hatcheries in the Mississippi Delta; Mississippi State University

RACNRAC-3: The Northeast Bivalve Hatchery Health Collaborative: Preventing Larval Mortalities in Northeast Hatcheries; The University of Rhode Island

RACNRAC-4: Identification of Hard Clams Resistant to HN Disease and Development of Diagnostic Test Methods; Roger Williams University

RACNCRAC-6: Improving Fish Health in the NCR by Integrating Extension with the Development of Alternative Disease Prevention Methods; Michigan State University

RACWRAC-1: Identification of genetic markers for disease resistance to infectious hematopoietic necrosis virus (IHNV) in commercial populations of rainbow trout through genome-wide association analysis; University of Washington

RACWRAC-2: Detection and control of mud blister worm (*Polydora* spp.) infestation on commercial oyster farms throughout the Pacific Northwest; The University of Washington

RACWRAC-3: Emerging and re-emerging Flavobacterial pathogens in aquaculture; The University of Idaho

RACWRAC-4: Development of oral vaccine delivery methods for prevention of disease in finfish culture; Oregon State University

RACCTSA-9: Assessment of Hawaiian Aquaculture for Disease Mitigation and Control; University of Hawaii

FDA Center for Veterinary Medicine (CVM)

Development of tools to monitor seafood safety. FDA leads, and USDA and NOAA are participants in, a technical advisory group that coordinates the development and validation of chemical detection methods for regulatory use. Needs for new analytical methods arise based on results of drug residue surveillance of imported and domestic farmed seafood and import tolerance requests.

Criteria to monitor for antimicrobial resistance. CVM in collaboration with six laboratories in the FDA Veterinary Laboratory Investigation and Response Network and four additional fish health laboratories finished standard antimicrobial susceptibility testing (AST) of nine economically important aquatic bacterial species against nine antimicrobials used in aquaculture. Data from seven of the species is being analyzed by CVM scientists to determine criteria used to identify if isolates of the bacteria have developed antimicrobial resistance. Data from the two other species was shared with European collaborators for similar analysis under existing projects. FDA and European colleagues will be proposing these new criteria to the Clinical Laboratory Standards Institute to be added to their guidelines on standard AST of bacteria isolated from aquatic animals.

The FDA Minor Use Minor Species Grant Program made one award for an aquaculture project this year. Intervet Inc. received a grant to help complete an environmental assessment for SLICE® (emamectin Type A medicated article) for the control of *Salmincola californiensis* on freshwater-reared *Oncorhynchus mykiss*.

FDA/CVM Aquaculture Strategic Plan. CVM continues to advance initiatives under its Aquaculture Strategic Plan, which identified the top aquaculture priorities for CVM to advance for fiscal years 2022-2026. Through this plan, CVM will develop and evaluate scientific and regulatory approaches that consider the unique needs of aquatic animals and aquaculture production systems, while also meeting the requirements of the Federal Food, Drug, and Cosmetic Act.

Animal and Veterinary Innovation Agenda. In September 2023, FDA released its Animal and Veterinary Innovation Agenda detailing CVM actions to foster product development and implement smart, risk-based approaches to regulating modern animal and veterinary products. The innovation agenda will facilitate development of technologies ranging from novel food ingredients to animal biotechnology products and aims to encourage the development of products for unmet human and animal needs including for aquaculture.

Guidance for Industry. In March 2023, the FDA finalized Guidance for Industry #106 on "The Use of Published Literature in Support of New Animal Drug Applications." The purpose of this document is to provide guidance to animal drug sponsors on specific areas of the approval process where the available scientific literature may be useful to support the approval of a new animal drug application, an abbreviated new animal drug application, or a conditionally approved new animal drug application, as well as methodologies to ensure the validity of conclusions drawn by animal drug sponsors from the scientific literature to support an approval.

In December 2023, the FDA finalized Guidance for Industry #61, "Special Considerations, Incentives, and Programs to Support the Approval of New Animal Drugs for Minor Uses and for Minor Species." This guidance is intended to assist those interested in pursuing FDA approval of these new animal drugs. It outlines the basic requirements and special considerations for approvals of MUMS drugs and describes the incentives available to encourage their development.

US Geological Survey

AquaDePTH: new project to develop an aquatic animal disease and pathogen repository. Currently, there is no infrastructure for sharing or tracking aquatic pathogen surveillance data at a regional or national scale. The Aquatic Disease and Pathogen Repository (AquaDePTH) will be a public-

facing national repository to support biosurveillance of aquatic animal diseases and pathogens. By collating historically published data, plus new aquatic pathogen and disease information, stakeholders will be able monitor fish kill and aquatic pathogen trends spatially and temporally in freshwater and marine environments. AquaDePTH-Aquatic Disease and Pathogen Repository | U.S. Geological Survey (usgs.gov)

Efficacy of florfenicol and oxytetracycline administered in feed to control cisco mortality associated with Aeromonas salmonicida infections. Two medications (one with florfenicol and one with oxytetracycline) are approved in the United States to control mortality due to furunculosis associated with *Aeromonas salmonicida.* A new publication assessed the efficacy of these antibiotics in medicated feeds to treat *A. salmonicida*-infected Cisco (also known as Lake Herring) *Coregonus artedi*. This study demonstrated that florfenicol- and oxytetracycline-medicated feeds were effective *A. salmonicida* treatments for Cisco. Outcomes may inform ongoing propagation efforts for Cisco restoration within the Great Lakes basin. 10.1002/naaq.10283

Efficacy of hydrogen peroxide to reduce Gyrodactylus species infestation density on four fish species. The ability to effectively treat parasitic infestations of fish is of high importance for fish culture facilities. However, tools or approved therapies for treating infestations on fish are limited. This paper summarizes results from four separate clinical field studies that evaluated the efficacy of hydrogen peroxide (H_2O_2; 35% PEROX-AID) for reducing *Gyrodactylus* spp. infestation density. Parasite density was significantly reduced for each parasite × host combination to which H_2O_2 therapy was applied. Two clinical field studies in salmonids were found to demonstrate substantial effectiveness that enabled 35% PEROX-AID approval. 10.1002/aah.10179

Infectious hematopoietic necrosis virus transmission models. Landscape infectious hematopoietic necrosis virus (IHNV) transmission dynamics previously had been estimated only for salmonid hatcheries in the Lower Columbia River Basin. University and USGS scientists estimated IHNV transmission dynamics in a unique geographic region, the Snake River Basin. Knowledge about hatchery complexes was held by a subset of project researchers but would not have been available to project modelers without coproduction. Model results indicated that in the Snake River, avoiding exposure to IHNV-positive adult salmonids is the most important action to prevent juvenile infections. Migrating adult salmonids exposed juvenile cohort-sites most frequently, and the infection probability was greatest following exposure to migrating adults. There is great potential for coproduction to advance understanding about infectious disease transmission in complex production systems and surrounding free-ranging animal populations. https://doi.org/10.1016/j.jenvman.2023.117415

Maternal immunity in trout following vaccination of broodstock against viral and bacterial pathogens. Infectious hematopoietic necrosis (IHN) is a significant viral disease affecting salmonids. *Flavobacterium psychrophilum*, the causative agent of bacterial coldwater disease, is one of the most significant bacterial pathogens of salmonids. University and USGS scientists explored maternal immunity for management of these two diseases in rainbow trout aquaculture. Two experimental trials were conducted where different groups of female broodstock were immunized prior to spawning with an IHNV DNA vaccine or a live attenuated *F. psychrophilum* vaccine, alone or in combination. Results suggest that maternal transfer of innate and adaptive factors at the transcript level occurred. In addition to documenting maternally derived immunity in teleosts, this study demonstrates that

broodstock vaccination can confer some degree of protection to progeny against viral and bacterial pathogens. https://doi.org/10.1016/j.fsi.2023.108749

An in vitro model to assess the toxicity of 6PPD-quinone in salmonids. The tire wear transformation product 6PPD-quinone (6PPDQ) has been implicated as the causative factor for broad scale mortality event for coho salmon in the Pacific Northwest. Highly variable sensitivity to 6PPDQ in closely related salmonids complicates efforts to evaluate the broader toxicological impacts to aquatic ecosystems. In a recent publication in *Environmental Science and Technology Letters*, scientists from USGS Western Fisheries Research Center and Kansas Water Science Center establish an *in vitro* cell line model for addressing 6PPDQ toxicity and its modes of action. https://doi.org/10.1021/acs.estlett.3c00196

Herpesvirus infections of sturgeon. Scientists from the Department of Fisheries and Oceans Canada, USGS Western Fisheries Research Center, Manitoba Hydro, Canadian Food Inspection Agency, Manitoba Agriculture, and others published an article titled "A New Sturgeon Herpesvirus from Juvenile Lake Sturgeon *Acipenser fulvescens* Displaying Epithelial Skin Lesions" in the journal *Pathogens* as part of the special issue on emerging infections in aquatic animals. The newly detected alloherpesvirus has potential to cause lethal disease outbreaks and reduce production success in threatened hatchery-reared sturgeon species. https://doi.org/10.3390/pathogens12091115

Susceptibility of endangered pallid sturgeon to virus. Scientists from the USGS Western Fisheries Research Center and USFWS Bozeman Fish Health Center published an article in the *Journal of Aquatic Animal Health* describing the first investigation assessing the susceptibility of endangered pallid sturgeon *Scaphirhynchus albus* to viral hemorrhagic septicemia virus (VHSV). Results suggested that the sturgeon could be infected with the highly lethal VHSV-IVb strain. However, because the tested fish had an underlying infection with a sturgeon nucleocytoplasmic large DNA virus, historically named Missouri River sturgeon iridovirus, further research needs to be conducted to determine the vulnerability of pallid sturgeon to VHSV-IVb alone. https://doi.org/10.1002/aah.10181

Advanced measurement methods to assess impact of PFAS on aquatic animal health. The newly established PFAS (perfluoroalkyl and polyfluoroalkyl substances) laboratory at the USGS Eastern Ecological Science Center, Leetown Research Laboratory, validated and finalized a 41-compound plasma analytical method. This plasma method will support the analytical needs of researchers studying PFAS bioaccumulation, biomagnification, and ecotoxicity related to aquatic animal health. Ongoing work includes testing and validating targeted methods for water and tissues, as well as workflows for non-targeted analysis. https://www.usgs.gov/programs/environmental-health-program/science/advanced-pfas-measurement-methods

Potential health effects of contaminant mixtures from point and nonpoint sources on aquatic animals. Aquatic ecosystems convey complex contaminant mixtures from anthropogenic pollution on a global scale. Point (e.g., municipal wastewater) and nonpoint sources (e.g., stormwater runoff) are both drivers of contaminant mixtures in aquatic habitats. The objectives of this study were to identify the contaminant mixtures present in surface waters impacted by both point and nonpoint sources, to determine if aquatic biota (amphibian and fish) health effects (testicular oocytes and parasites) occurred at these sites, and to understand if differences in biological and chemical measures existed between point and nonpoint sources. These findings are critical to support the conservation,

protection, and management of a wide range of aquatic species in the Pinelands and elsewhere as habitat loss, alteration, and fragmentation increase with increasing development. https://www.sciencedirect.com/science/article/pii/S0048969722053049

17-ethinylestradiol exposure in bass results in differential susceptibility to bacterial infection. Disease outbreaks, skin lesions, mortality events, and reproductive abnormalities have been observed in wild populations of centrarchids. The presence of estrogenic endocrine disrupting compounds (EEDCs) has been implicated as a potential causal factor for these effects. The results of a laboratory study demonstrate that exposure to a model EEDC alters metabolism and immune function in largemouth bass, a fish species that is ecologically and economically important in North America. https://pubs.acs.org/doi/full/10.1021/acs.est.2c02250

A primer of pathology and infectious agents of unionid mussels. Freshwater mussels are one of the most imperiled groups of organisms in the world, and more than 30 species have gone extinct in the last century. While habitat alteration and destruction have contributed to the declines, the role of disease in mortality events is unclear. In an effort to involve veterinary pathologists in disease surveillance and the investigation of freshwater mussel mortality events, this publication provides information on the conservation status of unionids, sample collection and processing techniques, and unique and confounding anatomical and physiological differences. https://doi.org/10.1177/03009858231171666

Diagnostic assay to detect the bacterium Yokenella regensburgei in freshwater mussels. Recent bacteriological investigations of freshwater mussel mortality events in the southeastern U.S. have identified a variety of bacteria and differences in bacterial communities between sick and healthy mussels. In particular, *Yokenella regensburgei* and *Aeromonas* spp. have been shown to be associated with moribund mussels, although it remains unclear whether these bacteria are causes or consequences of disease. A molecular assay for the detection of *Yokenella* was developed and validated for use in future investigations of mussel mortality events and to identify environmental reservoirs of this bacterium. https://doi.org/10.3390/microorganisms11041068 April 2023

Mussel mortality events reveals a consistent association with Yokenella regensburgei. Pheasantshell mussels in the Clinch River (Tennessee/Virginia, USA) have declined dramatically in recent years. The bacterium *Yokenella regensburgei* was first isolated with high prevalence from pheasantshells during the peak of a 2017 mortality event, but it was not identified after mortality subsided a few months later. Since 2017, pheasantshell mortality in the Clinch River has occurred each autumn (2018-2020). *Y. regensburgei* was identified each year, almost exclusively during active mortality events. The significance of *Y. regensburgei* remains unclear, but the continued association of this bacterium with mussel mortality events warrants further study. https://doi.org/10.3390/microorganisms11041068

Bacterial gill disease in Pacific razor clam populations. Nuclear inclusion X (NIX), the etiological agent of bacterial gill disease in Pacific razor clams *Siliqua patula*, was associated with host mortality events in coastal Washington State, USA, during the mid-1980s. Ongoing observations of truncated razor clam size distributions in Kalaloch Beach, Washington, raised concerns that NIX continues to impact populations. Researchers conducted a series of spatial, longitudinal and temporal NIX surveys and compared pathogen variation to population estimates from stock assessments. The study findings

support the hypothesis that high NIX intensities are associated with host mortality. NIX-associated mortality appears to be more pronounced at Kalaloch Beach relative to other Washington beaches. https://doi.org/10.3354/dao03685

Causative agent of long-spined sea urchin die-off identified. USGS researchers, along with an international team of collaborators, identified the pathogen responsible for killing long-spined sea urchins (*Diadema antillarum*) across the Caribbean in 2022. A fatal pathogen affecting the long-spined sea urchin decimated populations of this important herbivore in the 1980s, which led to rapid degradation of coral in the affected regions. A similar disease emerged in the remaining *D. antillarum* in 2022, with disease signs very reminiscent of the disease seen nearly 40 years ago. The research team used a combination of approaches to identify a parasitic ciliate similar to *Philaster apodigitiformis* as the causative agent. This discovery is a key piece of information that reef managers can use to begin planning mitigation strategies. https://doi.org/10.1126/sciadv.adg3200

US Fish and Wildlife Service

The FWS Aquatic Animal Drug Approval Partnership (AADAP) continues to work with partners to obtain U.S. Food and Drug Administration (FDA) approval of safe and effective new drugs for use in aquaculture and fisheries management. In July of 2023, FWS, USGS, and NOAA renewed the memorandum of agreement with AFWA to continue to establish and describe responsibilities and facilitate cooperation among these agencies in coordinating and collaborating on research and data submittals to the FDA Center for Veterinary Medicine (CVM) for approval of priority drugs for use in public aquaculture in the United States. Also in fiscal year 2023, AADAP's National Investigational New Animal Drug (INAD) Program reactivated its Benzoak (benzocaine) INAD to pursue approval of this drug for sedation to handleable and began work to study Aqui-S 20E (eugenol) for extended light sedation. The INAD Team has established a new mini workshop for INAD participants consisting of 1-2 hour long webinars that are held with a specific organization or company to discuss the INAD process and answer any questions specific to the needs of those participants. In addition, AADAP's research program continues to conduct or assist partners with Effectiveness and Target Animal Safety studies to fulfill data needs required for drug approvals through the FDA. In 2023, the Research Team worked with the drug sponsor of a spawning aid to develop a target animal safety study protocol for establishing a margin of safety for this product when used to induce spawning in female catfish. Work was also conducted to develop an analytical method for measuring hydrogen peroxide (H2O2) concentration in open ocean net pens to remove external parasites. AADAP met with NOAA at their Southeast Science Center located in Galveston, TX in May and the Northwest Science Center in Manchester, WA in September to explore collaborations in specific saltwater drug approval projects that may be appropriate to these locations. In addition, AADAP worked with the Office of Minor Use and Minor Species within FDA to develop an Indexing Guide for both internal use and to assist sponsors in navigating FDA's Indexing process.

The FWS continues to play a role in the American Fisheries Society – Fish Health Section (AFS-FHS) update process for the AFS-FHS Bluebook: Suggested Procedures for the Detection and Identification of Certain Finfish and Shellfish Pathogens. This past year, FWS Fish Health staff provided input to the proposed restructuring of the Bluebook Inspection Standards Committee and Testing Standards Committee. Also in 2023 the full network of FWS Fish Health Centers achieved Tier 2 AFS Laboratory Certification.

Other work designed to protect the health of aquaculture species includes FWS aquatic invasive species (AIS) efforts. The FWS awarded a grant to Oregon State University to produce an after-action report of the actions taken to respond to the importation of zebra mussel contaminated moss ball products into the United States. The report will compile, and catalog existing statutes, regulations, and policies related to the response. A detailed case study will be developed detailing the invasive species legal framework, how that framework supported the response, the interplay of the state's response with the federal response, and the role (if any) local governments played in the response. The report will also identify gaps in federal authorities and regulations and identify opportunities for states to better align their responses to national-scale AIS import incidents. Anticipated completion of the report is in early 2024.

Susceptibility of pallid sturgeon to viral hemorrhagic septicemia virus genotype IVb. Objective: Viral hemorrhagic septicemia virus (VHSV) is an aquatic rhabdovirus causing severe disease in freshwater and saltwater fish species. The susceptibility of endangered pallid sturgeon, *Scaphirhynchus albus,* to VHSV genotype IVb (VHSVIVb) infection was investigated. Methods: An in vitro assessment using two pallid sturgeon cell lines derived from skin and spleen tissue and in vivo evaluation of juvenile pallid sturgeon after exposure to VHSV- IVb were performed. Result: Plaque assay and RT- PCR results confirmed VHSV- IVb replication in pallid sturgeon cell lines. Sturgeon were also susceptible to VHSV-IVb infection after immersion and injection exposures during laboratory experiments. However, after widespread mortality occurred in all treatment groups, including negative control fish, it was determined that the pallid sturgeon stock fish were infected with Missouri River sturgeon iridovirus (MRSIV) prior to experimental challenge. Nevertheless, mortalities were equal or higher among VHSV-exposed fish than among negative controls (MRSIV infected), and histopathological assessments indicated reduced hematopoietic cells in spleen and kidney tissues and hemorrhage in the gastrointestinal organs only in fish from the VHSV treatment. Conclusion: These results indicate that pallid sturgeon are a susceptible host for VHSV- IVb, but the degree of pathogenicity was confounded by the underlying MRSIV infection. Research comparing susceptibility of specific pathogen-free and MRSIV-infected fish to VHSV- IVb is needed to accurately assess the vulnerability of pallid sturgeon to VHSV- IVb. http://dx.doi.org/10.1002/aah.10181

Efficacy of Florfenicol and Oxytetracycline Administered in Feed to Control Cisco Mortality Associated with *Aeromonas salmonicida* Infections. Two medications (one with florfenicol and one with oxytetracycline) that are approved in the United States to control mortality due to furunculosis associated with *Aeromonas salmonicida* were assessed to determine their efficacy in medicated feeds to treat *A. salmonicida*-infected cisco (also known as Lake Herring) *Coregonus artedi*. Cisco were subjected to static infection baths containing *A. salmonicida* or a sham control and then were distributed to replicate test tanks within four treatment groups: (1) fish infected with *A. salmonicida* and treated with 15 mg florfenicol center dot kg body weight (BW)(-1)center dot d(-1), (2) fish infected with *A. salmonicida* and treated with 83 mg oxytetracycline center dot kg BW-1 center dot d(-1), (3) fish infected with *A. salmonicida* and treated with a nonmedicated control feed, and (4) uninfected fish treated with a nonmedicated control feed. Medicated and comparative nonmedicated feed rations were administered at 2% BW/d for 10 consecutive days in accordance with the U.S. Food and Drug Administration-approved drug label, followed by a 7-d postdosing observation period using only nonmedicated feed. Cisco that were infected with *A. salmonicida* and treated with florfenicol (79% survival) and oxytetracycline (85% survival) had significantly higher survival than *A. salmonicida*-infected fish that received no medicated treatment (3% survival). No statistical difference in cisco

survival between the two medicated feed types was found. *Aeromonas salmonicida* was not detected in the kidney tissue of any surviving fish treated with medicated feeds at 7 d postdosing using quantitative PCR analysis. Overall, this study demonstrated that florfenicol- and oxytetracycline-medicated feeds were effective *A. salmonicida* treatments for cisco. Outcomes may inform ongoing propagation efforts for cisco restoration within the Great Lakes basin. http://dx.doi.org/10.1002/naaq.10283

Plasticity, Paralogy, and Pseudogenization: Rhabdoviruses of Freshwater Mussels Elucidate Mechanisms of Viral Genome Diversification and the Evolution of the Finfish-Infecting Rhabdoviral Genera. Viruses in the family *Rhabdoviridae* infect a variety of hosts, including vertebrates, invertebrates, plants, and fungi, with important consequences for health and agriculture. This study describes two newly discovered viruses of freshwater mussels from the United States. Viruses in the family *Rhabdoviridae* display remarkable genomic variation and ecological diversity. This plasticity occurs despite the fact that, as negative sense RNA viruses, rhabdoviruses rarely if ever recombine. Here, we describe non-recombinatorial evolutionary processes leading to genomic diversification in the *Rhabdoviridae* inferred from two novel rhabdoviruses of freshwater mussels (Mollusca: Bivalvia: Unionida). Killamcar virus 1 (KILLV-1) from a plain pocketbook (*Lampsilis cardium*) is closely related phylogenetically and transcriptionally to finfish-infecting viruses in the subfamily *Alpharhabdovirinae*. KILLV-1 offers a novel example of glycoprotein gene duplication, differing from previous examples in that the paralogs overlap. Evolutionary analyses reveal a clear pattern of relaxed selection due to sub-functionalization in rhabdoviral glycoprotein paralogs, which has not previously been described in RNA viruses. Chemarfal virus 1 (CHMFV-1) from a western pearlshell (*Margaritifera falcata*) is closely related phylogenetically and transcriptionally to viruses in the genus *Novirhabdovirus,* the sole recognized genus in the subfamily *Gammarhabdovirinae*, representing the first known gammarhabdovirus of a host other than finfish. The CHMFV-1 G-L noncoding region contains a non-transcribed remnant gene of precisely the same length as the NV gene of most novirhabdoviruses, offering a compelling example of pseudogenization. The unique reproductive strategy of freshwater mussels involves an obligate parasitic stage in which larvae encyst in the tissues of finfish, offering a plausible ecological mechanism for viral host-switching. IMPORTANCE: Viruses in the family Rhabdoviridae infect a variety of hosts, including vertebrates, invertebrates, plants, and fungi, with important consequences for health and agriculture. This study describes two newly discovered viruses of freshwater mussels from the United States. One virus from a plain pocketbook (*Lampsilis cardium*) is closely related to fish-infecting viruses in the subfamily *Alpharhabdovirinae*. The other virus from a western pearlshell (*Margaritifera falcata*) is closely related to viruses in the subfamily *Gammarhabdovirinae*, which until now were only known to infect finfish. Genome features of both viruses provide new evidence of how rhabdoviruses evolved their extraordinary variability. Freshwater mussel larvae attach to fish and feed on tissues and blood, which may explain how rhabdoviruses originally jumped between mussels and fish. The significance of this research is that it improves our understanding of rhabdovirus ecology and evolution, shedding new light on these important viruses and the diseases they cause. http://dx.doi.org/10.1128/jvi.00196-23

Pathology and infectious agents of unionid mussels: A primer for pathologists in disease surveillance and investigation of mortality events. Freshwater mussels are one of the most imperiled groups of organisms in the world, and more than 30 species have gone extinct in the last century. While habitat alteration and destruction have contributed to the declines, the role of disease in mortality events is unclear. In an effort to involve veterinary pathologists in disease surveillance and the investigation of freshwater mussel mortality events, we provide information on the conservation

status of unionids, sample collection and processing techniques, and unique and confounding anatomical and physiological differences. We review the published accounts of pathology and infectious agents described in freshwater mussels including neoplasms, viruses, bacteria, fungi, fungal-like agents, ciliated protists, Aspidogastrea, Digenea, Nematoda, Acari, Diptera, and Odonata. Of the identified infectious agents, a single viral disease, *Hyriopsis cumingii,* plague disease, that occurs only in cultured mussels is known to cause high mortality. Parasites including ciliates, trematodes, nematodes, mites, and insects may decrease host fitness, but are not known to cause mortality. Many of the published reports identify infectious agents at the light or ultrastructural microscopy level with no lesion or molecular characterization. Although metagenomic analyses provide sequence information for infectious agents, studies often fail to link the agents to tissue changes at the light or ultrastructural level or confirm their role in disease. Pathologists can bridge this gap between identification of infectious agents and confirmation of disease, participate in disease surveillance to ensure successful propagation programs necessary to restore decimated populations, and investigate mussel mortality events to document pathology and identify causality. http://dx.doi.org/10.1177/03009858231171666

A review of lethal thermal tolerance among freshwater mussels (Bivalvia: Unionida) within the North American faunal region. Freshwater mussels of the order Unionida are currently one of the most imperiled groups of organisms in the North American faunal region. Accurate risk assessments and development of effective management strategies for remaining populations require knowledge of thermal limits in the face of increasing surface water temperature due to climate change and various anthropogenic factors. We conducted a systematic literature review of unionid mussels (order Unionida, families *Margaritiferidae* and *Unionidae)* in the North American faunal region to (1) summarize lethal thermal tolerance data by life stage and taxonomy, (2) discuss ecological and climate change implications of existing lethal tolerance data, and (3) identify needs for future research. We identified lethal tolerance estimates for only 28 of 302 species in the families *Unionidae* and *Margaritiferidae*. The mean acute median lethal temperatures were 32.8 degrees C for glochidia (19 species), 35.0 degrees C for juveniles (13 species), and 36.3 degrees C for adults (4 species). Generally, glochidia were less tolerant than juveniles or adults of the same species-but there were several exceptions. Generally, *Amblemini* had the highest acute and chronic thermal tolerance of all tribes followed by *Anodontini, Pleurobemini, Lampsilini,* and *Quadrilini*. Acclimation temperature affected lethal tolerance endpoints in less than half (52 of 145) of comparisons within species. Lethal tolerance data for additional species, combined with a comprehensive database of in situ surface water temperatures, would be useful for modeling the frequency and duration of lethal limit exceedance in North America and identifying populations currently living at or near their upper lethal limits. http://dx.doi.org/10.1139/er-2022-0077

Responses to pathogen exposure in sentinel juvenile fall-run Chinook salmon in the Sacramento River, CA. This study investigated how the deployment of juvenile Chinook salmon in ambient river conditions and the subsequent exposure to and infection by pathogens was associated with the changes in the expression of genes involved in immune system functioning, general stress, and host development. Juvenile fish were deployed in sentinel cages for 21 days in the Sacramento River, CA, USA. Gill, kidney, and intestinal tissue were sampled at 0-, 7-, 14- and 21-days post-deployment. Pathogen detection and host response were assessed by a combination of molecular and histopathological evaluation. Our findings showed that fish became infected by the parasites *Ceratonova shasta*, *Parvicapsula minibicornis* and *Ichthyophthirius multifiliis*, and to a lesser extent, the

bacteria *Flavobacterium columnare* and *Rickettsia*-like organisms. Co-infection was common among sentinel fish. Expression of investigated genes was altered following deployment and was often associated with pathogen abundance. This study provides a foundation for future avenues of research investigating pathogens that affect out-migrating Chinook salmon in the Sacramento River, and offers crucial knowledge related to conservation efforts. http://dx.doi.org/10.1093/conphys/coad066

Mussel mass mortality in the Clinch River, USA: metabolomics detects affected pathways and biomarkers of stress. We compared metabolomic profiles of pheasantshell (*Ortmanniana pectorosa)* from a reoccurring mass mortality event in the Clinch River, Virginia and Tennessee, USA, and identified potential biomarkers and metabolic pathways indicative of health status. Biologists monitoring freshwater mussel (order Unionida) populations rely on behavioral, often subjective, signs to identify moribund (sick) or stressed mussels, such as gaping valves and slow response to probing, and they lack clinical indicators to support a diagnosis. As part of a multi-year study to investigate causes of reoccurring mortality of pheasantshell (*Ortmanniana pectorosa*; synonym *Actinonaias pectorosa*) in the Clinch River, Virginia and Tennessee, USA, we analyzed the hemolymph metabolome of a subset of mussels from the 2018 sampling period. Mussels at the mortality sites were diagnosed in the field as affected (case) or unaffected (control) based on behavioral and physical signs. Hemolymph was collected in the field by non-lethal methods from the anterior adductor muscle for analysis. We used ultra-high-performance liquid chromatography with quadrupole time-of-flight mass spectroscopy to detect targeted and untargeted metabolites in hemolymph and compared metabolomic profiles by field assessment of clinical status. Targeted biomarker analysis found 13 metabolites associated with field assessments of clinical status. Of these, increased gamma-linolenic acid and N-methyl-l-alanine were most indicative of case mussels, while adenine and inosine were the best indicators of control mussels. Five pathways in the targeted analysis differed by clinical status; two of these, purine metabolism and glycerophospholipid metabolism, were also indicated in the untargeted analysis. In the untargeted analysis, 22 metabolic pathways were associated with clinical status. Many of the impacted pathways in the case group were catabolic processes, such as degradation of amino acids and fatty acids. Hierarchical clustering analysis matched clinical status in 72% (18 of 25) of mussels, with control mussels more frequently (5 of 16) not matching clinical status. Our study demonstrated that metabolomic analysis of hemolymph is suitable for assessing mussel condition and complements field-based indicators of health. http://dx.doi.org/10.1093/conphys/coad074

NOAA Sea Grant

Via the FY23 competition "Aquaculture Technologies and Education Travel Grants Projects," the following project was established:

- Training and educating auditors, extension agents and regulators on the Regional Shellfish Seed Biosecurity Program

Via FY23 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing workforce development/training projects:

- Phytoplankton dynamics and shellfish health – NHSG
- Temperature effects on shellfish - WASG

NOAA National Marine Fisheries Service

Disease issues frequently result in substantial economic losses within the aquaculture industry. The prevention and control of disease is crucial for all sectors including fish, shellfish, and seaweeds. NMFS

seeks to support research projects that protect the health and well-being of aquaculture species through the following grant programs and other support:

FY23 Saltonstall-Kennedy grant program:

- Understanding pathogen dynamics in shellfish nurseries as a basis for expanding the Regional Shellfish Seed Biosecurity Program to nursery settings

Supported NMFS regional science centers with funding for the following projects:

- Predictive tools combining oceanography and ecology with epidemiology to limit spread of diseases in aquaculture -- first example modeling OsHV-1uvar in the Pacific Oyster, *Crassostrea gigas*
- Flow cytometric analysis of hemocyte immune functions in the Pacific Oyster (*Crassostrea gigas*) in response to in vitro exposure to bacterial probiotic strain OY15: Confirmation of immune stimulation as the mechanism of OY15's beneficial effects on survival, fitness and increased settlement of Pacific oyster larvae seen during hatchery-scale trials.
- Characterizing early immune system development and generating live attenuated vaccine candidates to prevent furunculosis caused by atypical *Aeromonas salmonicida*: Key tools for improving aquatic animal health and welfare in sablefish.
- Efficacy of "Ovaplant-L" for induction of maturation, spawning, and synchronization of reproduction in sablefish broodstocks.

National Science Foundation

Award # 2212614, SBIR Phase I: Adapting uncrewed aquaculture management to control sea lamprey and to protect wild salmonid fisheries of the Great Lakes, Robert Huber, RADMANTIS LLC, 02/01/2023 – 06/30/2024, TIP Directorate, Translational Impacts (TI)

Objectives: This Small Business Innovation Research (SBIR) Phase I project focuses on improved methods for detecting and suppressing sea lampreys in the Great Lakes, a pest species that currently requires relentless, sustained, and costly control efforts at ecosystem scale. The project initiates the development of small, relocatable, field-deployed devices, capable of performing a range of assessment and selective control functions. Success in this effort will introduce an important new tool to bolster environmental health outcomes at an ecosystem level, and benefit commercial fisheries estimated at $7B annually. By replacing chemical and manual control of exotic invaders, the project contributes to the preservation of ecosystem integrity and function, biodiversity, and environmental quality of the Great Lakes, a vital natural resource providing water security for more than 35 million people in the region.

Award # 2222310 + 2345023, Collaborative Research: ORCC: Carryover effects of multiple climate change stressors in oysters: mechanisms and consequences across stages of ontogeny, Thomas Miller, University of Maryland Center for Environmental Sciences, and Sarah Donelan, University of Massachusetts, Dartmouth, 12/01/2022 – 11/30/2026, Directorate for Biological Sciences, Organismal Responses to Climate Change.

Objective: This study uses the eastern oyster (*Crassostrea virginica*) to experimentally test how early life exposure to ocean warming and low dissolved oxygen affects oysters' responses to these same stressors later in life. The findings will improve understanding of how repeated stress exposure affects species' responses to climate change, and whether repeated exposure is a tool that can be harnessed to improve food and job security in aquaculture and resource management.

Objective 3.2: Promote the safety and nutritional value of U.S. aquaculture products

USDA Animal and Plant Health Inspection Service Veterinary Services
Cooperative agreement with Crosby Marketing Communications to develop, launch and communicate an aquaculture campaign focused on the health of U.S. farm-raised aquatic livestock.

USDA National Institute of Food and Agriculture
2023-67021-39749: Integrative Multi-Omics to Elucidate Mechanisms and Implications of Microbiome Evolution to Agi-Food Nanomaterials in Food System; The University of Florida

2023-67017-39184: Thermal Inactivation Of Norovirus In Oyster: Quantifying the Risks Associated With Residual Viruses; The University of Florida

2023-70020-40630: Developing a Hazards and Controls Guide to Support Safe Seaweed Production and Marketing; Cornell University

2023-69015-39605: PARTNERSHIP: Increasing trout consumption in young children and families for cognitive and mental health benefit; The University of Idaho

RACNRAC-2: Impact of Waterbirds of Fecal Coliform Levels at Floating Gear Oyster Aquaculture Operations; University of Rhode Island

RACNCRAC-3: Comprehensive Study of Processing Fish in Local Facilities for Local Food Systems; Purdue University

FDA Center for Food Safety and Applied Nutrition (CFSAN)
FDA and Federal Partners Launch Study on the Role of Seafood Consumption in Child Growth and Development. The U.S. Food and Drug Administration (FDA) announced the launch of an independent study by the National Academies of Sciences, Engineering, and Medicine (NASEM) on the *Role of Seafood Consumption in Child Growth and Development*. The FDA is partnering with the National Oceanic and Atmospheric Administration, U.S. Department of Agriculture, and U.S. Environmental Protection Agency on this study, which supports the goals of the FDA's Closer to Zero Action Plan for reducing the exposure of babies and young children to mercury, arsenic, lead, and cadmium from foods.
This study is designed to provide the most up-to-date understanding of the science of seafood consumption and child growth and development. Better understanding the science on mercury exposure from food is an important step in the cycle of continual improvement in the FDA's Closer to Zero Action Plan. The study will also help inform whether updates are needed for the current Advice about Eating Fish for children and those who might become or are pregnant or breastfeeding.

Guidance for Industry. CFSAN is drafting a Guidance for Industry for Safe Growing, Harvesting, Packing, Processing, Handling, and Distribution of Seaweed for Human Consumption. The guidance is intended to provide harvesters and processors guidance regarding the food safety hazards associated with wild and aquacultured seaweed intended for human consumption.

NOAA Sea Grant

Via the FY23 competition "Aquaculture Technologies and Education Travel Grants Projects," the following projects were established:

- Primary processing bottlenecks: addressing barriers for small to medium-scale seaweed production in the United States
- Culinary exchange in support of the scallop farming industry in Maine and the northeast US

NOAA National Marine Fisheries Service

Ensuring that aquaculture products are safe for human consumption is critical in establishing consumer confidence and a stable market environment. NMFS seeks to address product safety by funding research projects through the following grant programs:

FY23 Interstate Marine Fisheries Commissions Pilot Project grant program:

- Overcoming challenges in commercial U.S. marine aquaculture: Development of post-harvest processing and value-add methods for tropical seaweed species in the Gulf and U.S. Caribbean

Supported the following project focused on developing strategies to protect the health and well-being of aquaculture species through the FY23 Small Business Innovation Research Phase II grant program:

- In situ and point of sale quantification of human pathogens associated with aquaculture and shellfish farming using novel surface enhanced raman spectroscopy

FY23 Saltonstall-Kennedy grant program:

- Development and optimization of farmer-run test kits to improve oyster safety

National Science Foundation

Award # 2329826, PFI-RP: BioSPACE: Biosensing Surveillance of Pathogens in Aquaculture and Coastal Environments, Yan Luo, University of Massachusetts Lowell, 09/01/2023 – 08/31/2026, TIP Directorate, Translational Impacts (TI)

Objective: The project advances the application of a novel biosensing-based data analytics platform for aquaculture and water-based environmental monitoring. Regular monitoring for pathogens is critical in safeguarding public and ecosystem health, and in supporting aquaculture sustainability and market growth. The project will substantially improve the ability to monitor waterborne pathogens in coastal environments and in the aquaculture industry.

Publications, Technology Transfer and Other Information

USDA ARS Agricultural Research Service

Engle, C., Hanson, T., Kumar, G. 2022. Economic history of U.S. catfish farming: Lessons for growth and development of aquaculture. Aquaculture Economics & Management. 26(1):1-35. https://doi.org/10.1080/13657305.2021.1896606.

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Mischke, C.C., Richardson, B.M., Tiwari, A., Griffin, M.J., Wise, D.J., Rehman, J.U., Ashfaq, M.K., Nanayakkara, P., Khan, I.A. 2022. Copper toxicity to the ghost rams-horn snail *Biomphalaria havanensis*. North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10279.

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US Fish and Wildlife Service

Relevant 2023 FWS Research Publications

NOAA Sea Grant Publications

Publications in 2023 resulting from NOAA Sea Grant funded projects– please note this list is not yet comprehensive for 2023

Mechanism	#
Peer Reviewed Journal Articles	13
Environmental Assessments	1
Sea Grant Publications	3
Strategic Plans	3

Almada, Amalia et al. (2023). A Deep Ocean DDT+ Research Needs Assessment for the Southern California Bight. University of Southern California. Sea Grant Institutional Program. https://doi.org/10.25923/e9y9-y115

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NOAA National Marine Fisheries Service

Publications in 2023 from NMFS-supported research and partnerships. This list should not be considered comprehensive.

Mechanism	# New
Peer-Reviewed Journal Articles	13
NOAA Technical Memoranda	2
Book Chapters	2
Final Reports	2

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