PROGRESS TOWARDS THE NATIONAL STRATEGIC PLAN FOR AQUACULTURE RESEARCH (2022)

PREPARED BY THE

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

SUBCOMMITTEE ON AQUACULTURE

SCIENCE PLANNING TASK FORCE

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Caird Rexroad, USDA, Chair

Mark Rath, DOC

Chuck Weirich, DOC

Ken Riley, DOC

Nikola Garber, DOC

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David Hu, DOI

M. Camille Hopkins, DOI

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Ciro Ruiz-Feria, FDA

Jennifer Matysczak, FDA

Ruth Shuman, NSF

Shivaun Leonard, USAID

Gene Kim, USDA

Jean Porter, USDA

Timothy Sullivan, USDA

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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
CFSAN	Center for Food Safety and Applied Nutrition
CVM	Center for Veterinary Medicine
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
EERE	Office of Energy Efficiency 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	United States 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: Develop 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.

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. Report to the President of the United States from the Rask Force on Agriculture and Rural Prosperity, 2017

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

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.

USDA National Institute of Food and Agriculture

Provided support to the Maine Aquaculture Innovation Center to investigate consumer preferences of seaweed products.

Provided support to Virginia Seafood AREC to use market research to guide U.S. aquaculture recovery in anticipation of the end of the COVID pandemic.

Provided support to the Atlantic Corporation to create an assessment and planning tool set to identify market opportunities for domestic farm-raised finfish and shellfish.

Provided support to VitaminSea LLC. to investigate the technical and market feasibility of kelp meal as a nutritional supplement in low moisture foods.

Provided support to a multistate committee focused on Marketing, trade, and management of aquaculture and fishery resources.

Provided support to the University of Florida to investigate structural changes in fish and seafood markets.

Provided support to Kentucky State University to advance sustainable systems for Kentucky farmers to produce and consistently market quality aquaculture products.

Provided support to Rutgers to improve the capacity and profitability of US Aquaculture by matching practical seafood product attributes with anticipated post-pandemic consumer demand.

US Geological Survey

Aquatic foods to nourish nations. Despite contributing to healthy diets for billions of people, aquatic foods are often undervalued as nutritional sources because their diversity is often reduced to the protein and energy value of a single food type ('seafood' or 'fish'). We created a cohesive model that unites terrestrial foods with nearly 3,000 taxa of aquatic foods to understand the future impact of aquatic foods on human nutrition. We project two plausible futures to 2030: a baseline scenario with moderate growth in aquatic animal-source food (AASF) production, and a high-production scenario with a 15-million-tonne increased supply of AASFs over the business-as-usual scenario in 2030, driven largely by investment and innovation in aquaculture production. By comparing changes in AASF consumption between the scenarios, we elucidate geographic and demographic vulnerabilities and estimate health impacts from diet-related causes. Globally, we find that a high-production scenario will decrease AASF prices by 26% and increase their consumption, thereby reducing the consumption of red and processed meats that can lead to diet-related non-communicable diseases, while also preventing approximately 166 million cases of inadequate micronutrient intake. This finding provides a broad evidentiary basis for policy makers and development stakeholders to capitalize on the potential of

aquatic foods to reduce food and nutrition insecurity and tackle malnutrition. https://doi.org/10.1038/s41586-021-03917-1

NOAA Sea Grant

Via the fiscal year (FY) 21 competition "Addressing Economic and Marketing Needs of the U.S. Aquaculture Industry," 12 ongoing projects were established to advance the understanding of the economics of aquaculture businesses and provide the industry with important market information to aid sustainable growth in the U.S. Specific projects focused on aquaculture markets include:

- Collaboratively Tracking Shellfish Aquaculture Production Data in Washington State
- Developing Farm and Market Tools for Shellfish Mariculture in North Carolina
- Business and Economic Planning for Seaweed Aquaculture Systems in the United States
- Economics of Risk in U.S. Aquaculture Production and Markets
- Utilizing an Aquaculture Industry Collaborative to Increase Hawaii's Resilience and Food Security
- Economic Status and Contribution of U.S. Aquaculture: Analyzing Viability Structures, Economic Impact, and Management Measures for Future Success
- Expanding Maine's Blue Economy
- Determining Market Potential for Food-Fish Aquaculture in Minnesota
- The Aquaculture Explorer Platform: Integrated Spatial-Financial Tools to Catalyze Aquaculture Investment

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," continued to support 11 Hubs established in FY19. Of these Hubs, the following are conducting aquaculture market related research:

- The Sea Grant StriperHub: Commercial Striped Bass Aquaculture Phase II
- Nurturing the Successful Growth and Maturation of a Domestic Seaweed Aquaculture Industry: Phase II
- Supporting Industry Needs Through Maine Aquaculture Hub
- Continuation of Aquaculture Hub: Building Capacity of Land-Based Atlantic Salmon Aquaculture in the U.S.
- Advancing the Great Lakes Aquaculture Collaborative

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing aquaculture market-related projects:

- Massachusetts Seafood Consumer Survey
- Growing roots for a Sustainable Seafood Hub in South Central Los Angeles, California
- Expanding Ohio Consumer-focused Aquaculture Outreach and Education and Building Community Collaborations
- Understanding the Economic Impact of Food-Based Tourism Opportunities Provided by the North Carolina Oyster Trail and Increasing Public Awareness

Via FY22 funding through Sea Grant Program competitions, the following aquaculture market related projects are ongoing:

- Outreach Training & Marketing (CTSG)
- Addressing Critical Aquaculture-Marketing-Oriented Applied Research and Outreach (Phase 2, IL/INSG)
- Market-Driven Production for Sustainable Aquaculture in Illinois and Indiana (IL/INSG)

- Identifying Value-Added Markets for Louisiana's Wild and Farm Alligator Industry (LASG)
- Expanding Maine's Blue Economy (MESG)
- Safe and Sustainable Seafood - Objective 4 (MESG)

NOAA National Marine Fisheries Service

Supported the following projects focused on identifying market opportunities through the FY21 and FY22 Saltonstall-Kennedy grant program:

- Kachemak Bay Kelp Processing & Distribution Hub: Removing a Bottleneck to Growth in the Alaska Seaweed Industry
- Hybridization in Clams to Achieve Efficiency and Larger Markets
- Economic and environmental feasibility of soft-shell clam aquaculture in Virginia
- Know Thy Oysters: Evaluating the Effectiveness of Seafood Server Training Programs to Increase Sales of American Seafood

Supported the following project focused on identifying market opportunities through the FY21 Small Business Innovation Research Phase II grant program:

- Tide to Table Traceability and Marketing System

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

US Environmental Protection Agency

The EPA Office of Research and Development (ORD) provides robust research and scientific analyses to innovatively and economically support safe and adequate supplies of water to protect people's health and livelihood while restoring and maintaining watersheds and aquatic ecosystems. Recent ORD products that can support a science-based approach to management of aquaculture include improved national watershed and water quality model capability, assessment of nutrient-related stressors and responses in freshwater and coastal habitats, approaches for understanding nutrients and nutrient-related impacts in coastal ecosystems across space and time, novel methods to assess the status of nutrient-sensitive aquatic life endpoints and nutrient indicators, and tools to support attainment of water quality goals.

US Geological Survey

Characterizing mauka-to-makai connections for aquatic ecosystem conservation on Maui, Hawai'i. Mauka-to-makai (mountain to sea in the Hawaiian language) hydrologic connectivity – commonly referred to as ridge-to-reef – directly affects biogeochemical processes and socioecological functions across terrestrial, freshwater, and marine systems. The supply of freshwater to estuarine and nearshore environments in a ridge-to-reef system supports the food, water, and habitats utilized by marine fauna. In addition, the ecosystem services derived from this land-to-sea connectivity support social and cultural practices (hereafter referred to as socio-cultural) including fishing, aquaculture, wetland agriculture, religious ceremonies, and recreational activities. To effectively guide island resource management, a better understanding of the linkages from ridge-to-reef across natural and social usages is critical, particularly in the context of climate change, with anticipated increasing temperature and shifting precipitation patterns. The objective of this study was to identify spatial linkages that promote multiple and diverse uses, following the ridge-to-reef concept, at an island-wide scale to identify regions of high conservation importance for aquatic resources. We selected the Island of Maui as a study representative of many Pacific islands. Diverse datasets, including agricultural lands within watersheds, wetland locations, presence of stream species, indicators of freshwater input from streams, coral cover, nearshore fish biomass, socio-cultural data such as fishpond locations, wetland taro cultivation, beach recreation use, and lastly the dynamically downscaled Coupled Model Intercomparison Project Phase (CMIP5) future climate projections scenarios (Representative Concentration Pathway (RCP) 4.5 & 8.5) were used to examine the spatial linkages through hydrological connectivity from land to the sea. Zonation spatial planning software was used to prioritize areas of high management and conservation value and to help inform aquatic resources management. The resulting prioritized areas included many minimally disturbed watersheds in east Maui and western nearshore and coastal zones that are adjacent to diverse coral reefs. These results are driven by the importance of fish biomass and coral reef distribution as well as traditional wetland taro cultivation and coastal access points for recreation. These results underline the importance of examining ridge-to-reef systems for aquatic resource management and including important social and cultural values in resource management upon planning adaptation strategies for climate change. Improving our understanding of diverse natural and socio-cultural influences on habitat conditions and their values in these areas provides an opportunity to strategically plan future management and conservation actions. https://doi.org/10.1016/j.ecoinf.2022.101704

Divergence in salinity tolerance of northern Gulf of Mexico eastern oysters under field and laboratory exposure. The eastern oyster, *Crassostrea virginica*, is a foundation species within US Gulf of Mexico (GoM) estuaries that has experienced substantial population declines. As changes from management and climate are expected to continue to impact estuarine salinity, understanding how local oyster populations might respond and identifying populations with adaptations to more extreme changes in salinity could inform resource management, including restoration and aquaculture programs. Wild oysters were collected from four estuarine sites from Texas [Packery Channel (PC): 35.5, annual mean salinity, Aransas Bay (AB): 23.0] and Louisiana [Calcasieu Lake (CL): 16.2, Vermilion Bay (VB): 7.4] and spawned. The progeny were compared in field and laboratory studies under different salinity regimes. For the field study, F1 oysters were deployed at low (6.4) and intermediate (16.5) salinity sites in Alabama. Growth and mortality were measured monthly. Condition index and *Perkinsus marinus* infection intensity were measured quarterly. For the laboratory studies, mortality was recorded in F1 oysters that were exposed to salinities of 2.0, 4.0, 20.0/22.0, 38.0 and 44.0 with and without acclimation. The results of the field study and laboratory study with acclimation indicated that PC oysters are adapted to high-salinity conditions and do not tolerate very low salinities. The AB stock had the highest plasticity as it performed as well as the PC stock at high salinities and as well as Louisiana stocks at the lowest salinity. Louisiana stocks did not perform as well as the Texas stocks at high salinities. Results from the laboratory studies without salinity acclimation showed that all F1 stocks experiencing rapid mortality at low salinities when 3-month oysters collected at a salinity of 24 were used and at both low and high salinities when 7-month oysters collected at a salinity of 14.5 were used. https://doi.org/10.1093/conphys/coab065

Tolerance of northern Gulf of Mexico eastern oysters to chronic warming at extreme salinities. The eastern oyster, *Crassostrea virginica*, provides critical ecosystem services and supports valuable fishery and aquaculture industries in northern Gulf of Mexico (nGoM) subtropical estuaries where it is grown subtidally. Its upper critical thermal limit is not well defined, especially when combined with extreme salinities. The cumulative mortalities of the progenies of wild *C. virginica* from four nGoM estuaries differing in mean annual salinity, acclimated to low (4.0), moderate (20.0), and high (36.0) salinities at 28.9 °C (84 °F) and exposed to increasing target temperatures of 33.3 °C (92 °F), 35.6 °C (96 °F) or 37.8 °C (100 °F), were measured over a three-week period. Oysters of all stocks were the most sensitive to increasing temperatures at low salinity, dying quicker (i.e., lower median lethal time, LT50) than at the moderate and high salinities and resulting in high cumulative mortalities at all target temperatures. Oysters of all stocks at moderate salinity died the slowest with high cumulative mortalities only at the two highest temperatures. The F1 oysters from the more southern and hypersaline Upper Laguna Madre estuary were generally more tolerant to prolonged higher temperatures (higher LT50) than stocks originating from lower salinity estuaries, most notably at the highest salinity. Using the measured temperatures oysters were exposed to, 3-day median lethal Celsius degrees (LD50) were estimated for each stock at each salinity. The lowest 3-day LD50 (35.1–36.0 °C) for all stocks was calculated at a salinity of 4.0, while the highest 3-day LD50 (40.1–44.0 °C) was calculated at a salinity of 20.0. https://doi.org/10.1016/j.jtherbio.2021.103072

How many Ciscoes are needed for stocking in the Laurentian Great Lakes? Historically, Cisco *Coregonus artedi* and deepwater ciscoes *Coregonus* spp. were the most abundant and ecologically important fish species in the Laurentian Great Lakes, but anthropogenic influences caused nearly all populations to collapse by the 1970s. Fishery managers have begun exploring the feasibility of restoring populations throughout the basin, but questions regarding hatchery propagation and stocking remain.

We used historical and contemporary stock-recruit parameters previously estimated for Ciscoes in Wisconsin waters of Lake Superior, with estimates of age-1 Cisco rearing habitat (broadly defined as total ha ≤ 80 m depth) and natural mortality, to estimate how many fry (5.5 months post-hatch), fall fingerling (7.5 months post-hatch), and age-1 (at least 12 months post-hatch) hatchery-reared Ciscoes are needed for stocking in the Great Lakes to mimic recruitment rates in Lake Superior, a lake that has undergone some recovery. Estimated stocking densities suggested that basin-wide stocking would require at least 0.641-billion fry, 0.469-billion fall fingerlings, or 0.343-billion age-1 fish for a simultaneous restoration effort targeting historically important Cisco spawning and rearing areas in Lakes Huron, Michigan, Erie, Ontario, and Saint Clair. Numbers required for basin-wide stocking were considerably greater than current or planned coregonine production capacity, thus simultaneous stocking in the Great Lakes is likely not feasible. Provided current habitat conditions do not preclude Cisco restoration, managers could maximize the effectiveness of available production capacity by concentrating stocking efforts in historically important spawning and rearing areas, similar to the current stocking effort in Saginaw Bay, Lake Huron. Other historically important Cisco spawning and rearing areas within each lake (listed in no particular order) include: (1) Thunder Bay in Lake Huron, (2) Green Bay in Lake Michigan, (3) the islands near Sandusky, Ohio, in western Lake Erie, and (4) the area near Hamilton, Ontario, and Bay of Quinte in Lake Ontario. Our study focused entirely on Ciscoes but may provide a framework for describing future stocking needs for deepwater ciscoes. https://doi.org/10.3996/JFWM-21-025

Behavior and Survival of Hatchery Rainbow Trout (Oncorhynchus mykiss) in the Upper Cowlitz River Basin, Washington, 2013 and 2017. A two-year study (2013 and 2017) was conducted to determine if annual releases of hatchery rainbow trout (resident *Oncorhynchus mykiss*) in the upper Cowlitz River Basin, Washington adversely affected anadromous fish in the basin. Rainbow trout tagged with radio transmitters were monitored after release to describe movement patterns, entrainment rates at Cowlitz Falls Dam, and survival. Additionally, trout that were radio-tagged in 2017 were monitored during spring 2018 to determine if any moved upstream and entered tributaries where winter steelhead (anadromous Oncorhynchus mykiss) spawning occurs. A total of 580 hatchery rainbow trout (122 in 2013 and 458 in 2017) were radio-tagged and released at three release sites: (1) Cowlitz Falls Campground on Cowlitz River Arm of Lake Scanewa river kilometer (rkm) 155, (2) Cispus River Arm of Lake Scanewa rkm 1, and (3) Day Use Park on Cowlitz River Arm of Lake Scanewa rkm 146. Most radio-tagged trout (70 percent) remained within 6.4 rkm of the release site but some fish moved at least 25.7 rkm from the release site. The predominant movement direction was downstream. More than twice as many fish released at Cowlitz Falls Campground in 2017 (compared to the other two release sites) remained in the Cowlitz River, where potential overlap with steelhead occurs. A total of 28.3 percent of the study fish were entrained at Cowlitz Falls Dam. Apparent survival (time until movement ceased) for most tagged trout was fewer than 100 days from release in both years and no fish were detected moving during the spring following their release. In summary, hatchery rainbow trout released upstream from Cowlitz Falls Dam seem to remain primarily in Lake Scanewa or entrained at Cowlitz Falls Dam with few fish surviving to winter months. We found no evidence of hatchery trout interacting with steelhead in spawning tributaries during spring months. These results suggest that trout stocking in the upper Cowlitz River Basin poses minimal threat to anadromous fish in the basin. https://doi.org/10.3133/ofr20211085

US Fish and Wildlife Service

USFWS contributions include an update to the Title 50 (T50) website to streamline the process for partners importing salmonids (https://www.fws.gov/service/steps-importing-salmonids-united-states-america) and efforts to increase the number of Certifying Officials. Additionally, the National Wild Fish Health Survey geospatial mapper was updated to provide better access to culturists to view USFWS pathogen detections in wild populations of fish nationwide (https://www.fws.gov/story/2022-08/wild-fish-health-survey-protecting-wild-fisheries).

Using appropriations from the Bipartisan Infrastructure Law to the Department of Interior (DOI), the USFWS, in collaboration with other DOI bureaus, awarded a grant to Conservation Collaborations LLC to develop an action plan to mitigate the risks of AIS trade and transport through commerce. A component of the action plan will identify regulatory gaps nationally and regionally, and provide specific regulatory language to federal agencies, Tribes, and the states to implement laws that address aquatic invasive species sold through commerce. The project will also develop an online toolkit for industry sellers to ensure accessible information about restricted species in each state as well as information about best management practices and responsibilities associated with buying aquatic species. Anticipated completion of the project is September 2024.

NOAA Sea Grant

Via the FY 21 competition "Addressing Economic and Marketing Needs of the U.S. Aquaculture Industry," the following project involves activities focused on aquaculture regulation/policy:

- The Aquaculture Explorer Platform: Integrated Spatial-Financial Tools to Catalyze Aquaculture Investment

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following include projects investigating/streamlining aquaculture regulation/policy:

- Nurturing the Successful Growth and Maturation of a Domestic Seaweed Aquaculture Industry: Phase II
- Advancing the Great Lakes Aquaculture Collaborative
- Continued Support for Expanding the Atlantic and Gulf Shellfish Seed Biosecurity Collaborative

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including aquaculture regulation/policy activities:

- Advancing Smart and Sustainable Aquaculture Growth in Rhode Island
- Development and Refinement of the California Aquaculture Action Plan

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects include aquaculture regulation/policy activities:

- Supporting a Sustainable Aquaculture Industry in Minnesota (MNSG)
- Safe and Sustainable Seafood - Objective 3 (MESG)
- Cooperative Research Monitoring and Education to Assist the Aquaculture Industry with Maintaining and Enhancing Production and Adapting to Changing Conditions (WHSG)

NOAA National Marine Fisheries Service

Supported the following projects focused on aquaculture regulation and policy improvements through the FY22 Interstate Commissions Pilot Project grant program:

- Advancing the viability of oil rig associated aquaculture
- Mapping and Aerial Survey of Kelp Beds in Southeast Alaska to Establish Baseline Abundance and Inform Kelp Farm Site Selection, Seed Stock Sources, and Outplanting Schedules

Supported the following projects focused on aquaculture regulation and policy improvements through the FY22 Small Business Innovation Research Phase II grant program:

- Artificial Intelligence Model and Platform for Automated Detection and Mapping of Intertidal Vegetation
- Deep Space Artificial Intelligence - A Deep-Learning Based Environmental Monitoring System Using Satellite Imagery

Supported NMFS regional science centers with funding for the following projects focused on aquaculture regulation and policy improvements:

- Expanding OMEGA modeling through macroalgal model development and Aquaculture Opportunity Area Programmatic Environmental Impacts Statements risk analysis assessments
- Measuring Social Acceptance for US Aquaculture
- Quality and Valuation of Habitat-Related Ecosystem Services Provided by Oyster Aquaculture Gear, and Development of Tools for Management

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

USDA Agricultural Research Service

ARS aquaculture scientists mentored 17 students/post docs, served in 5 adjunct appointments at universities, conducted or participated in 5 outreach events to a total of 315 students, and 8 other outreach events to 422 non-student participants.

USDA National Institute of Food and Agriculture

Provided support to Texas State University for "Bluewater", a smart circular economy for Hydroponic/Aquaponic farming to empower an underrepresented workforce.

Provided support to Carteret Community College to strengthen an aquaculture workforce development pipeline in Coastal North Carolina.

Provided support to the Gulf of Maine Research Institute to establish a comprehensive workforce training system for Maine's aquaculture sector.

Provided support to the Maine Aquaculture Innovation Center to develop training systems for the next generation of Maine's aquaculture workforce.

Provided support to the Marine and Environmental Research Institute of Pohnpei to provide technical assistance, extension, and training for beginning aquaculture farmers in Hawaii, Micronesia, and American Samoa. This included actions additional actions related to COVID19 response.

Provided support to Delaware State University for a training program to support an emerging Delaware shellfish industry.

Provided support to Oregon State University to extend food safety training to frontline communicators with seafood processors.

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following projects are conducting aquaculture training/education/workforce development activities:

- Advancing Southern New England Shellfish Aquaculture Through an Engaged Public and Next Generation Decision Support Tools (Extension Through 2024) Connecticut Sea Grant
- Hawai'i-Pacific Aquaculture Consortium: Continuing the Expansion of an Aquaculture Development Program
- Supporting Industry Needs Through Maine Aquaculture Hub
- Continuation of Aquaculture Hub: Building Capacity of Land-Based Atlantic Salmon Aquaculture in the U.S.
- Advancing the Great Lakes Aquaculture Collaborative
- The Sea Grant StriperHub: Commercial Striped Bass Aquaculture Phase II North Carolina Sea Grant
- Advancing the Cross-Pacific Indigenous Aquaculture Collaborative
- West Coast Aquaculture Collaborative

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including aquaculture training/education/workforce development activities:

- Retention of Aquaculture Extension Associate (GUSG)
- Commercial Oyster Aquaculture Sector Training (COAST) Program (MASGC)
- Sustaining the North Carolina Shellfish Farming Academy

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects include training/education/workforce development activities:

- Supporting a Sustainable Aquaculture Industry in Minnesota (MNSG)
- S.C. Sea Grant Extension Program: Sustainable Fisheries and Aquaculture (SCSGC)
- Extension and Education - Supporting Florida's Aquaculture Businesses (FLSG)
- Maryland Sea Grant Extension Program: Sustainable Fisheries and Aquaculture (MDSG)
- Exploring and Expanding Michigan's Aquaculture Industry (MISG)
- Extension - Shellfish Aquaculture (NJSGC)
- Project 6 – Aquaculture (TXSG)
- Research and Education to Support Development of Open-Water Restorative and Production Aquaculture in Hilo Bay (HISG)
- Aquaculture Outreach Uw-Stevens Point-Northern Aquaculture Demonstration Facility Red Cliff WI (WISG)
- Technical Assistance for Shellfish Seaweed and Indigenous Aquaculture (WASG)

NOAA National Marine Fisheries Service

Through a joint effort between NOAA and USDA, an Aquaculture Information Exchange (AIE) was developed to serve as an online community resource for public, non-profit and private sectors with interests in a wide variety of domestic aquaculture topics and serves to promote the growth of a sustainable aquaculture industry.

Supported the following projects focused on aquaculture training, education, and workforce development through the FY22 Interstate Commissions Pilot Project grant program:

- Intensive practical training of women in Integrative Multi-Trophic Aquaculture: Towards a sustained mariculture workforce in Puerto Rico
- Alaska Mariculture Initiative
- Na'boka: Battling Hunger through Community-Driven Aquaculture Projects

Supported the following projects focused on aquaculture training, education, and workforce development through the FY21 and FY22 Saltonstall-Kennedy grant program:

- Community Science to Support Sustainable and Local Seafood Production in Maine
- Empowering growers while growing capacity: Research, testing, and training to address microbiological impediments on shellfish aquaculture
- Establishing a Supply and Training Program for Aquaculture Production of Hawaiian Sea Cucumber
- Building resiliency in tribal fishing communities: Using Indigenous aquaculture techniques to enhance clam production

National Science Foundation

The GEOPath Informal Networks: Alaska Aquaculture Science Knowledge, led by the Sitka Sound Science Center, is providing aquaculture educational experiences to pre-college rural and Alaska Native students to transition successfully into undergraduate programs or directly into the STEM workforce. The award was co-funded, through July 2024, by the Directorate for Geological Sciences Division of Research, Innovation, Synergies, and Education (RISE), the EDU Improving Undergraduate STEM Education (IUSE) initiative, and the Established Program to Stimulate Competitive Research (EPSCoR).

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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

Texture differences between channel and hybrid catfish. Hybrid catfish are increasingly used in U.S. aquaculture production, so an assessment of product quality and comparison to channel catfish is critical for meeting consumer expectations. Using instrumental texture analysis, ARS scientists in New Orleans, Louisiana, showed differences between the cooked fillets of channel and hybrid catfish, and found that fillet freezing and storage methods (e.g., individually quick-frozen (IQF), fresh, or frozen) affected texture. Firmness, toughness, and chewiness were most associated with the catfish type, and hybrids had lower levels than channels. Other texture attributes were indicative of the cold-storage methods; IQF fillets had higher cohesiveness and lower adhesiveness, and both frozen and IQF fillets had higher springiness attributes. Scientists will need to study genetics, environment, and pond management practices to better understand how these factors affect product quality and to improve attributes that meet consumer expectations.

Improved sex reversal in rainbow trout. Most of the rainbow trout industry depends upon production of all-female fish for grow-out. The maintenance of all-female lines depends upon creating genetic "XX" females that produce male gametes, or sperm, a process that involves supplementing feed with male steroids for 60 days. Drawbacks of this approach include 1) the need to surgically remove testes to access the sperm because the sex-reversed fish seldom develop functional sperm ducts that enable sperm to migrate from the male testes, and 2) the cost of infrastructure to prevent steroid releases into the environment. ARS researchers in Leetown, West Virginia, developed an improved approach to sex reversal by exposing female fry to male steroids through immersion rather than feeding. Treatment consisting of seven 1-hour weekly immersions in the steroid beginning at 4-7 days after hatching greatly reduced the number of fish with sperm duct abnormalities, avoiding the need to euthanize fish to surgically remove testes to harvest sperm, and preventing environmental contamination by enabling the steroid to be easily captured from the immersion bath. Review and approval of this drug would be required by FDA before commercial application.

Improved growth in North American Atlantic salmon smolt. Commercial salmon farming is rapidly expanding in the United States, so selectively bred North American stocks that can compete with European imports are needed. A higher weight at smolt usually results in a faster time to market and a higher chance of survival. When ARS researchers in Franklin, Maine, began selectively breeding salmon in 2007, the average weight at smolt was 65 grams per fish. After four generations of selecting for growth, the average weight at smolt more than doubled at 167 grams per fish. This improved germplasm has been transferred to industry stakeholders and will have an immediate economic impact on reducing the time to market and improving profitability.

Marker-assisted selection for resistance to bacterial cold-water disease. Bacterial cold-water disease (BCWD) is one of the most devastating diseases in rainbow trout aquaculture. Improving resistance to BCWD using traditional family-based selective breeding or genomic selection with markers spanning the entire genome is promising but limited, because these methods are labor intensive, costly, and the resistance trait cannot be measured directly in potential breeders. For these reasons, marker-assisted selection is advantageous because it can directly and relatively inexpensively predict the genetic merit of potential breeding animals using just a small number of DNA markers. ARS researchers in Leetown, West Virginia, identified a set of six DNA markers that can be used to predict the

genetic merit of breeding animals just as accurately or even more accurately than the traditional family-based selective breeding approaches for genomic selection. Using these markers is simpler and less expensive, and the effectiveness of this approach was demonstrated in a commercial breeding population, indicating that it can further improve the efficiency and sustainability of rainbow trout aquaculture in the United States.

Advances in yellowtail amberjack spawning and nutrition. The domestic yellowtail amberjack is a consumer favorite, and there are ongoing efforts to increase production by establishing offshore farms. However, the industry is challenged by the need for year-round production of juveniles to stock these farms and efficient diets for feeding spawning fish to produce efficient, hardy, and robust juveniles. Researchers in Fort Pierce, Florida and Hubbs Sea World Research Institute (California) collaborators established methods for the successful out of season spawning of yellowtail broodstock. In addition, the team demonstrated that commercially available diets can be used to produce high egg and larval quality and quantities to make the U.S. industry competitive. This accomplishment contributes to the year-round availability of a consistently high-quality product.

Identifying founder stocks for a Florida pompano broodstock program. When establishing a new selective breeding program, it is essential to understand the genetic makeup of the parents to maximize diversity in the gene pool and avoid contaminating the existing gene pool. Researchers at Harbor Branch Oceanographic Institute found that wild populations of Florida pompano off the Atlantic/East Coast of Florida and the Gulf/West Coast of Florida are genetically similar, which suggests they are one population. This provides a greater understanding of the genetic variation found in the wild and informs the collection of broodstock for initiating a selective breeding program to improve production efficiency.

USDA National Institute of Food and Agriculture

Provided support to The University of Texas at Austin for the enhancement of male southern flounder broodstock fertility by direct activation of sperm 2nd messenger pathways downstream of mPRalpha.

Provided support to the University of Maine to establish metrics of broodstock and offspring quality in Atlantic Salmon aquaculture.

Provided support to the University of Alabama at Birmingham to improve rainbow trout growth performance through optimization of diet epigenetic interactions.

Provided support to West Virginia State University for the characterization of phenotypic and genetic relationships between digestive efficiency and gut microbiome composition in rainbow trout fed vegetable- or insect-based ingredient sources.

Provided support to Ocean Era, Inc. to develop tools to enable induction of early maturation to accelerate selective breeding outcomes in *Seriola rivoliana*.

Provided support to Symbrosia, Inc. to enable breeding and improvement of red macroalgae *Asparagopsis taxiformis* for enhanced yields.

Provided support to Texas A&M University to enable the building of a foundation for genetic improvement of Eastern oysters in Texas.

Provided support to Kentucky State University for genetic evaluation of alternative aquaculture species.

Provided support to Rutgers University for the genetic improvement of eastern oysters.

Provided support to the University of Florida for the application of sperm cryopreservation technology in oyster genetic breeding.

Provided support to Louisiana State University for phenotypic testing and scoring of eastern oyster populations for use as broodstock for the Northern Gulf of Mexico oyster aquaculture industry.

US Geological Survey

Development of aquaculture protocols and gonadal differentiation of red shiner. Developing detailed rearing methods and describing the onset of gonadal differentiation in Red Shiners *Cyprinella lutrensis* could facilitate the development of novel techniques to control or enhance populations, enable toxicology studies, and help construct bioassays. In this study, we develop and report aquaculture practices for Red Shiner that ensure consistent year-round production in laboratory settings and evaluate the timing of sexual differentiation via histological gonad examinations. Our methods resulted in a mean of 56.00% (SD = 8.98%) survival through the larval stages of development, and we obtained spawns from captive-reared Red Shiners 138 d posthatch. Red Shiners are gonochoristic, and both ovaries and testes differentiate directly from undifferentiated gonads. Ovaries begin to differentiate in females 45 d posthatch, while testes begin differentiating in males 105 d posthatch. This study provides in-depth protocols for the closed-cycle aquaculture of Red Shiners and describes the gonadal differentiation and development of both sexes. https://doi.org/10.1002/naaq.10176

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following projects involve conducting genetics research:

- Enhancing the Sustainability of the East Coast Hard Clam Selective Breeding Collaborative (Hub Part 2)
- The Sea Grant StriperHub: Commercial Striped Bass Aquaculture Phase II

Via the FY22 competition "Early Stage Propagation Strategies for Aquaculture Species," of the 9 projects funded, the following projects involve conducting genetics research:

- Universal Hatchery System for Developing new Seaweed Strains for Land-Based Aquaculture Production
- Genomic Approach to Improve Reproductive Performance of Pacific White Shrimp, *Litopenaeus vannamei*
- Domestication and Breeding of Lumpfish to Accelerate Successful Commercialization and use for Sea Lice Biocontrol in the Northeast US
- Developing Sporeless (Infertile) Breeds of Domesticated Kelp Species to Reduce Regulatory Barriers for Expanded Kelp Farming

Via the FY22 competition "Marine Finfish Aquaculture: Juvenile Production Technologies," of the 4 projects funded, the following projects involve conducting genetics research:

- Maximizing the Quantity and Quality of California Yellowtail (*Seriola dorsalis*) Produced Consistently in Intensive Larval Rearing Systems
- Resolving Impediments to Captive Longevity and Fecundity in Seriolids, America's Most Successful Offshore Marine Fish Species
- Sea Grant StriperHub: Commercial Striped Bass Hatchery, Fingerling Production, and Intensive Larval Rearing

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including genetics research:

- Development of a Genetic-Based Testing Service to Support Virginia and Mid-Atlantic Hard Clam Breeding Industry Members
- Support of VIMS Marine Advisory Program
- Fine-Scale Genetic Monitoring of Eastern Oyster Population Structure for Aquaculture, Fisheries Management, and Restoration (TXSG)
- Striped Bass Aquaculture: Enhanced Captive Breeding Strategies through Identification of Sex Pheromones in Striped Bass, *Morone saxatilis* (NCSG)

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects include genetics research:

- Applying Indigenous Knowledge and Genetic Data to Evaluate Clam Garden Restoration Potential in Northern California (CASG)
- Against All Odds: Development of Bay Scallop Strains that Resist Temperature and Disease Stress (NYSG)
- Sustaining Marine Forests: A Genomics and Experimental Approach to Inform Bull Kelp Restoration Aquaculture and Conservation

NOAA National Marine Fisheries Service

Supported the following project to advance genetics research through the FY22 Interstate Commissions Pilot Project grant program:

- Selective Breeding for Ocean Acidification tolerant stocks of farmed Blue Mussel in Pacific Southwest

Supported the following projects to advance genetics research through the FY21 and FY22 Saltonstall-Kennedy grant program:

- Hybridization in Clams to Achieve Efficiency and Larger Markets
- A transcriptomic study of the differential stress response between diploid and triploid eastern oyster *Crassostrea virginica*, and its potential involvement in triploid mortality
- Influence of selective breeding on human pathogenic *Vibrio* spp. in eastern oysters
- Understanding Triploid Pacific Oyster Mortalities on the U.S. West Coast

Supported NMFS regional science centers with funding for the following projects focused to advance genetics research:

- Advancing genetics, breeding and genomics for adaptation of shell phenotypes and byssal ability in mussels for offshore aquaculture and climate change
- Organize and host the 4th Seriola Workshop in January 2023
- Applying cutting-edge technology for production of sterile shellfish
- Refinement of methods for monosex production and sterilization of sablefish

National Science Foundation

Through the Translational Impacts program of the Directorate for Technology, Innovation and Partnerships (TIP), support was provided to the Louisiana State University Agricultural Center in Baton Rouge for "Open hardware for aquatic germplasm preservation" a project to establish germplasm repositories to safeguard the genetic resources of aquatic species.

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

USDA Agricultural Research Service

New method detects off-flavor in water and fish tissue. An increase in U.S. land-based aquaculture systems to produce Atlantic salmon and other fish is expected and will require methods to monitor off-flavor to ensure fish products are acceptable to consumers. Off-flavor compounds from bacterial and fungal metabolites can accumulate in fish tissues and result in unpalatable "earthy" or "muddy" flavors. Previous methods to detect off-flavor compounds could only process 10 samples a day and cost $120 per sample. University of Maine researchers and ARS scientists in Franklin, Maine, developed a new method of detecting geosmin and 2-methylisoborneol, two compounds that cause off-flavor in water and fish tissues. The new method can process at least 40 samples per day at a cost of $40 per sample. This lower cost is more affordable for fish farmers, enabling them to provide consumers with consistently high-quality products.

USDA National Institute of Food and Agriculture

Provided support to the University of Washington for improved climate resilience in oysters through optimization of hatchery-based conditioning practices

Provided support to Rutgers University for an evaluation of the impacts of environmental change on the sustainability of oyster fisheries and aquaculture.

Provided support to the University of the District of Columbia for the use of life-cycle sustainability assessment to measure environmental, economic, and societal impacts of aquaculture and aquaponics.

FDA Center for Food Safety and Applied Nutrition (CFSAN)

Enhanced diagnostic tools for species identification. Ensuring that all seafood is correctly labeled and identified is a priority for FDA. This includes providing information and educational aid on species identification tools to the industry and to our regulatory partners both domestic and abroad. FDA currently uses a DNA-based method commonly referred to as DNA Barcoding as its primary analytical tool for identifying seafood products for the purposes of misbranding and adulteration investigations and also in illness outbreak investigations to refine its hazards and controls guidance which is species specific for seafood. In an effort to provide transparency in our analytical methods and also to aid industry as well as our state and federal regulatory partners, standard operating procedures for DNA Barcode generation and DNA sequences for all FDA seafood species reference standards have been made publicly available through https://www.fda.gov/food/science-research-food/dna-based-seafood-identification. In addition, FDA continues to develop next generation species identification tools suitable for regulatory use such as the use of low coverage whole genome sequencing (a.k.a. genome skimming) to distinguish closely related species as well as species hybrids that are difficult to identify using many traditional species identification methods.

US Geological Survey

Modeling protected species distributions and habitats to inform siting and management of pioneering ocean industries: A case study for Gulf of Mexico aquaculture. Marine Spatial Planning (MSP) provides a process that uses spatial data and models to evaluate environmental, social,

economic, cultural, and management trade-offs when siting (i.e., strategically locating) ocean industries. Aquaculture is the fastest-growing food sector in the world. The United States (U.S.) has substantial opportunity for offshore aquaculture development given the size of its exclusive economic zone, habitat diversity, and variety of candidate species for cultivation. However, promising aquaculture areas overlap many protected species habitats. Aquaculture siting surveys, construction, operations, and decommissioning can alter protected species habitat and behavior. Additionally, aquaculture-associated vessel activity, underwater noise, and physical interactions between protected species and farms can increase the risk of injury and mortality. In 2020, the U.S. Gulf of Mexico was identified as one of the first regions to be evaluated for offshore aquaculture opportunities as directed by a Presidential Executive Order. We developed a transparent and repeatable method to identify aquaculture opportunity areas (AOAs) with the least conflict with protected species. First, we developed a generalized scoring approach for protected species that captures their vulnerability to adverse effects from anthropogenic activities using conservation status and demographic information. Next, we applied this approach to data layers for eight species listed under the Endangered Species Act, including five species of sea turtles, Rice's whale, smalltooth sawfish, and giant manta ray. Next, we evaluated four methods for mathematically combining scores (i.e., Arithmetic mean, Geometric mean, Product, Lowest Scoring layer) to generate a combined protected species data layer. The Product approach provided the most logical ordering of, and the greatest contrast in, site suitability scores. Finally, we integrated the combined protected species data layer into a multi-criteria decision-making modeling framework for MSP. This process identified AOAs with reduced potential for protected species conflict. These modeling methods are transferable to other regions, to other sensitive or protected species, and for spatial planning for other ocean-uses. https://doi.org/10.1371/journal.pone.0267333

Development of aquaculture protocols and gonadal differentiation of green sunfish (*Lepomis cyanellus*). We provide detailed rearing methods and describe green sunfish (*Lepomis cyanellus*) gonadal development and histological differentiation for both sexes. Developing in-depth aquaculture protocols and describing the gonadal differentiation of green sunfish could facilitate strategies to control nuisance populations, enhance stocking programs, and provide information for this species' use in bioassay trials or toxicology studies. Our methods resulted in consistent year-round production of green sunfish and allowed us to identify the timing of their gonadal differentiation through histological assessment. Our spawning methods provided year-round volitional spawns from green sunfish broodstock. Our rearing methods involved weaning larval green sunfish off live nauplii and onto only artificial diets by 37 days post-hatch (dph). Most of the offspring generation reached sexual maturity by 213 dph. Green sunfish are gonochoristic, with testes and ovaries differentiating directly from undifferentiated gonads. Ovaries begin to differentiate by 39 dph and testes begin to differentiate by 69 dph. This information can provide biologists consistent means to produce this Centrachid and understand their gonadal development.
https://doi.org/10.1016/j.aquaculture.2021.737515

Decades of global sturgeon conservation efforts are threatened by an expanding captive culture industry. After centuries of overexploitation and habitat loss, many of the world's sturgeon (Acipenseridae) populations are at the brink of extinction. Although significant resources are invested into the conservation and restoration of imperiled sturgeons, the burgeoning commercial culture industry poses an imminent threat to the persistence of many populations. In the past decade, the number and distribution of captive sturgeon facilities has grown exponentially and now encompasses diverse interest groups ranging from hobby aquarists to industrial-scale commercial facilities.

Expansion of sturgeon captive culture has largely fallen outside the purview of existing regulatory frameworks, raising concerns that continued growth of this industry has real potential to jeopardize conservation of global sturgeon populations. Here, we highlight some of the most significant threats commercial culture poses to wild populations, with particular emphasis on how releases can accelerate wild population declines through mechanisms such as hybridization, introgression, competition, and disease transmission. We also note that in some circumstances, commercial captive culture has continued to motivate harvest of wild populations, potentially accelerating species' declines. Given the prevalence and trajectory of sturgeon captive culture programs, we comment on modifications to regulatory frameworks that could improve the ability of captive culture to support wild sturgeon conservation. https://doi.org/10.1002/fsh.10865

Declining diversity of wild-caught species puts dietary nutrient supplies at risk. Although biodiversity loss adversely influences a variety of ecosystem functions, how declining wild food diversity affects nutrient supplies for people is poorly understood. We analyze the impact of declining biodiversity on nutrients supplied by fish using detailed information from the Peruvian Amazon, where inland fisheries provide a critical source of nutrition for many of the region's 800,000 people. We found that the impacts of biodiversity loss on nutrient supplies depended on compensation, trophic dynamics, and functional diversity. When small sedentary species compensated for declines in large migratory species, fatty acid supplies increased, while zinc and iron supplies decreased. In contrast, the probability of failing to maintain supplies or nutrient supply risk increased when species were nutritionally unique. Our results show that trait-based regulations and public health polices need to consider biodiversity's vital role in sustaining nutritional benefits for over 2 billion people dependent on wild foods across the globe. https://doi.org/10.1126/sciadv.abf9967

Surface water with more natural temperatures promotes physiological and endocrine changes in landlocked Atlantic salmon smolts. Hatchery salmonid smolts are often reared using groundwater with elevated temperatures to maximize growth. Previous work has shown that rearing hatchery smolts in surface water with a more natural thermal regime resulted in increased return rates of adult landlocked Atlantic salmon (*Salmo salar*). We evaluated whether landlocked Atlantic salmon reared in surface water with a natural temperature regime have altered physiological smolt characteristics compared with fish reared in groundwater with elevated winter temperatures. Hatchery fish were sampled three consecutive years from January to May. Additional fish were released as smolts, recaptured, and compared with fry-stocked smolts. Surface water smolts had earlier peaks of plasma T4, lower T3 levels, later peak cortisol, and lower gill Na+/K+-ATPase activity as compared with groundwater smolts. After release and recapture, surface water fish had elevated plasma T4 and gill Na+/K+-ATPase activity compared with groundwater fish, but less than stream-reared fish. Elevated plasma T4 in surface water fish in the hatchery and after release may have promoted imprinting and other aspects of smolt development, contributing to the higher adult return rates of a cohort reared in surface water. https://doi.org/10.1139/cjfas-2020-0295

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following projects involve conducting production technologies research:

- Enhancing the Sustainability of the East Coast Hard Clam Selective Breeding Collaborative (Hub Part 2)

- Continuation of Aquaculture Hub: Building Capacity of Land-Based Atlantic Salmon Aquaculture in the U.S.
- Supporting Industry Needs Through Maine Aquaculture Hub Maine Sea Grant
- The Sea Grant StriperHub: Commercial Striped Bass Aquaculture Phase II North Carolina Sea Grant

Via the FY22 competition "Early Stage Propagation Strategies for Aquaculture Species," of the 9 projects funded, the following projects involve conducting production technologies research:

- Universal Hatchery System for Developing New Seaweed Strains for Land-Based Aquaculture Production
- Addressing Bottlenecks and Refining Commercial Culture of *Amphiprion ocellaris* Florida Sea Grant
- "Cracking the Shell": A Collaborative Approach to Developing Hatchery Production of the Atlantic Sea Scallop, *Placopecten magellanicus*

Via the FY22 competition "Marine Finfish Aquaculture: Juvenile Production Technologies," of the 4 projects funded, the following project involves conducting production technologies research:

- Sea Grant StriperHub: Commercial Striped Bass Hatchery, Fingerling Production, and Intensive Larval Rearing

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including production technologies research:

- Pilot Program in which Engineering Students and Aquaculture Practitioners are Brought Together to Create Solutions to Problems that Require Robotic Physical Intervention (MITSG)
- Moving Towards a More Economically Viable Land-based Aquaculture Industry in Vermont (LCSG)
- Continuous Measurement of Valve Movements to Monitor Grow-out Conditions of Farmed Oysters (LASG)
- Identifying the Winter Thermal Requirements for Successful Reproduction of Walleye (*Sander vitreus*) (WISG)
- Striped Bass Aquaculture: Enhanced Captive Breeding Strategies through Identification of Sex Pheromones in Striped Bass, *Morone saxatilis* (NCSG)

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects including production technologies research:

- Designs in Infrastructure and Best Management Practices to Improve Alternative Oyster Culture Farming in Response to Threats from Extreme Weather Events (LASG)
- Velella Epsilon: Pioneering Offshore Aquaculture in the Southern Gulf Of Mexico - Phase II (FLSG)
- Optimizing the Full Cycle Aquaculture Production of Red Snapper *Lutjanus campechanus* for Technology Transfer to the Private Sector (FLSG)
- Safe and Sustainable Seafood - Objective 2 (MESG)
- Implementation of Low-Cost Conductive Yarn Sensors into Aquaculture Enclosures for Strand and Rope Integrity Monitoring (MITSG)
- Oystermaran Ii: Autonomous Surface Vehicles for Maintenance and Intervention in Aquaculture Farming to Improve Occupational Health and Safety (MITSG)
- Real-Time Environment and Aquaculture Structure Load/ Motion Predictions through Physic-Informed Machine Learning (MITSG)

- Diversifying the New England Sea Vegetable Aquaculture Industry - Phase II: Line Seeding Technology and Growout (NHSG)
- Multi-Trophic Waste Management for Finfish Mariculture in Land-Based Recirculating Aquaculture Systems using the Salt-Tolerant Halophyte *Salicornia virginica* (NCSG)
- CRISPR- Based Portable Biosensor System for On-Site Detection of Fish Pathogens (OHSG)
- Sustainable Aquaculture of Sea Vegetables in Puerto Rico for Local Cuisines and Coastal Restoration (PRSG)
- Resolving the Diet of Marine Fish Larvae to Accelerate Aquaculture Opportunities II (HISG)
- Development of Practical Feed for Walleye Aquaculture (WISG)
- 2022 Virginia Sea Grant Aquaculture Supplemental (VASG)

NOAA National Marine Fisheries Service

Supported the following research projects focused on production technologies to increase environmentally responsible food production and contribute ecosystem services through the FY22 Interstate Commissions Pilot Project grant program:

- Advancing commercial-scale sustainable marine aquaculture: Identification and assessment of native seaweed species for aquaculture in the Gulf of Mexico and U.S. Caribbean Regions
- Automated marine mammal monitoring system for Manna Fish Farms Gulf of Mexico
- Tropical macroalgae nutrient uptake in finfish effluent water, and macroalgal marketability

Supported the following research projects focused on production technologies to increase environmentally responsible food production and contribute ecosystem services through the FY21 and FY22 Saltonstall-Kennedy grant program:

- Collective Grassroots Pathways Toward Restorative Aquaculture: Removing Invasives and Bringing Back Native Species
- Development of an Integrated Multitrophic Aquaculture System to Restore Hawaii's Vulnerable Limu (Seaweed) Populations
- Community Science to Support Sustainable and Local Seafood Production in Maine
- Virginia coast bay scallops, *Argopecten irradians*: aquaculture and wild restoration
- Enhancing Marine Aquaculture in the Tropical U.S.: Methods for sustainable commercial co-cultivation of shellfish and seaweed in Florida
- Collaboration with local fish processing industry to convert fish trimmings and skins into value added fish meal and fish oil to promote sustainability
- From nuisance to profit: Monetizing seaweeds and cockles that foul shellfish aquaculture farms

Supported the following research projects focused on production technologies to increase environmentally responsible food production and contribute ecosystem services through the FY22 Small Business Innovation Research Phase I and Phase II grant programs:

- Improving Data Measurements in Alaskan Waters While Reducing Ghost Gear Using Smart Fishing Technology
- Artificial Intelligence Model and Platform for Automated Detection and Mapping of Intertidal Vegetation
- Deep Space Artificial Intelligence - A Deep-Learning Based Environmental Monitoring System Using Satellite Imagery

Supported NMFS regional science centers with the following research projects focused on production technologies to increase environmentally responsible food production and contribute ecosystem services:

- Advancing genetics, breeding and genomics for adaptation of shell phenotypes and byssal ability in mussels for offshore aquaculture and climate change
- Opportunity Area Programmatic Environmental Impacts Statements risk analysis assessments
- Further Development of Macroalgae Feed Ingredients for Marine Fish
- Developing monitoring and mitigation strategies for Harmful Algal Blooms on Alaska oyster farms
- Quality and Valuation of Habitat-Related Ecosystem Services Provided by Oyster Aquaculture Gear, and Development of Tools for Management
- Suitability and efficacy of insect protein and lipids in finfish feeds
- Applying cutting-edge technology for production of sterile shellfish
- Herring Deterrent Strategies
- Refinement of methods for monosex production and sterilization of sablefish
- Habitat function of shellfish aquaculture ecosystems: in situ fish behavior and diets

National Science Foundation

Through the Convergence Accelerator program of the Directorate for Technology, Innovation and Partnerships (TIP), support was provided to San Diego State University, through September 2023, for "Developing Blue Economy from Micro to Macro-Scale in Kelp Aquaculture" with an overarching goal to enhance seaweed farming along the west coast of the USA. The project team is exploring the role of microbial communities and their gene functions in promoting seaweed health and nutritional and industrial quality, to determine whether these microbiomes can play a crucial role in expanding seaweed aquaculture. The team will travel to seaweed farms to train farmers in microbial sampling techniques, and ultimately build a "Guide for Best Practices" for seaweed farming that can be used by this expanding sector and will provide better information for the kelp aquaculture industry concerning best practices for farm management and ecosystem restoration, optimal farm designs and site locations, and approaches for increasing desirable attributes associated with seaweed aquaculture (polysaccharide and alginate production, carbohydrate and lipid production, heat shock resistance and overall biomass production yields).

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

Improving fecal stability and reducing nutrient leaching of rainbow trout feeds. Uneaten feed and fish feces release nutrients that enrich effluent waters from production systems, which can lead to algal blooms and other unintended consequences. Replacing fishmeal (FM) in rainbow trout diets with plant-based protein sources such as soybean meal (SBM) and soy protein concentrate (SPC) has compounded this problem, since these feeds can reduce fecal stability, increase fecal fine particles, and add nutrients to water. ARS researchers in Hagerman, Idaho and Bozeman, Montana determined that rainbow trout feeds comprised of a mixture of poultry byproduct meal (PBM), corn protein concentrate (CPC), and SPC with guar gum binder produced more stable feces characterized by larger fecal particles and fewer fine fecal particles, compared to standard fishmeal-based and commercial feeds. Large fecal particles are more easily collected, enabling nutrient capture and minimizing their release to the environment.

USDA National Institute of Food and Agriculture

Provided support to the University of California at Santa Cruz for the evaluation of conversion of under-utilized algal co-products into high quality aquaculture feed.

Provided support to Auburn University for the development of bacterial-algal-zooplankton process for conversion of agricultural waste into aquaculture feed.

Provided support to Central State University for the investigation of hemp as a sustainable and novel feed additive for salmonid aquaculture.

Provided support to USDA ARS for the advancement of the use of alfalfa leaf protein concentrate in aquaculture feeds.

Provided support to Global Algae Innovations, Inc for the development of algae production processes for aquaculture feeds.

Provided support to the University of Arizona for the development of PCR-based diagnostics in support of disease-free attestations in formulated aquafeed.

Provided support to West Virginia State University for investigations of the association of metabolic efficiency with mitochondrial oxidative function and fish gut microbiome for finfish consuming plant-derived aquafeeds.

Provided support to Cornell University for the development of sustainable silage-based feed for aquaculture.

US Geological Survey

Quantitative method development to determine feed consumption using a dye. Although there are many methods to determine ingestion and absorption of aquafeeds, none exist that are simple, cost-effective, and quantitative and that can mark fish with a long-lasting, visible indicator. In addition to aquafeed development, selective baits are needed that can be used for aquatic invasive species

removal efforts, including for Grass Carp Ctenopharyngodon idella. Bait incorporated with a pesticide would allow for selective removal of targeted species. A method to quickly assess multiple bait formulations was developed to expediate development for invasive species management. Incorporation of Sudan Black B (SBB) in aquafeeds at concentrations greater than 75 and 120 mg SBB/kg fish resulted in pigmented external soft tissues of Largemouth Bass Micropterus salmoides and Rainbow Trout Oncorhynchus mykiss, respectively, 24 h after consumption. Visual confirmation of consumption was detectable in the gastrointestinal tract at all concentrations tested (≥10 mg SBB/kg) and quantifiable by absorbance measured at 601 nm from extracted SBB in tissues at concentrations less than those required for visual pigmentation. Although SBB was detectable in multiple tissues, fin and mandible tissues yielded the greatest accuracy in estimating consumption from extracted SBB. Compared with other tissues tested, liver tissue accumulated the highest level of SBB but had the greatest variability, while muscle tissue accumulated little detectable SBB. We used the SBB analytical method to compare consumption of six novel baits that were in the initial developmental stages to produce a palatable bait formulation designed to attract Grass Carp for management control. Overwhelming preference of a rapeseed bait formulation was confirmed using SBB as a tracer of consumption in the laboratory; however, use of SBB under natural conditions may be valuable for answering additional questions. Baits incorporated with SBB allowed for the rapid, simultaneous assessment of multiple formulations and could allow for future refinement of management baits, with results available as quickly as 24–72 h after application. https://doi.org/10.1002/naaq.10246

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following project involves conducting nutrition research:

- The Sea Grant StriperHub: Commercial Striped Bass Aquaculture Phase II
- Via the FY22 competition "Early Stage Propagation Strategies for Aquaculture Species," of the 9 projects funded, the following projects involve conducting production technologies research:
- Addressing Bottlenecks and Refining Commercial Culture of Amphiprion ocellaris
- Domestication and Breeding of Lumpfish to Accelerate Successful Commercialization and use for Sea Lice Biocontrol in the Northeast US

Via the FY22 competition "Marine Finfish Aquaculture: Juvenile Production Technologies," of the 4 projects funded, the following projects involve conducting production technologies research:

- Sea Grant StriperHub: Commercial Striped Bass Hatchery, Fingerling Production, and Intensive Larval Rearing
- Maximizing the Quantity and Quality of California Yellowtail (*Seriola dorsalis*) Produced Consistently in Intensive Larval Rearing Systems
- Resolving Impediments to Captive Longevity and Fecundity in Seriolids, America's Most Successful Offshore Marine Fish Species
- Nutritional Strategies for Improved Larval Production of Marine Finfish with an Emphasis on *Seriola* sp.

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including nutrition research:

- Moving Towards a More Economically Viable Land-based Aquaculture Industry in Vermont (LCSG)
- Via FY22 funding through Sea Grant Program competitions, the following ongoing projects including nutrition research:

- Development of Practical Feed for Walleye Aquaculture (WISG)
- Eat Your Greens: Evaluating Microalgae Supplemented Feeds for Sablefish Nutrition and Growth (CASG)
- Utilizing Local Charleston, South Carolina Craft Brewery By-Products to Fill Nutritional Gaps in Sustainable Fish Feeds for Juvenile Red Drum, *Sciaenops ocellatus* (SCSGC)

NOAA National Marine Fisheries Service

Supported the following aquaculture projects focused on nutrition research through the FY21 and FY22 Saltonstall-Kennedy grant program:

- Developing Domestic Formulated Feeds and Sea Cucumber Polyculture Integration in California Abalone Aquaculture
- Collaboration with local fish processing industry to convert fish trimmings and skins into value added fish meal and fish oil to promote sustainability
- Liposome-based microparticles for improved nutrition and production efficiency of marine fish larvae

Supported the following aquaculture projects focused on nutrition research through the FY22 Small Business Innovation Research Phase I grant program:

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

Supported NMFS regional science centers with the following aquaculture projects focused on nutrition research:

- Further Development of Macroalgae Feed Ingredients for Marine Fish
- Suitability and efficacy of insect protein and lipids in finfish feeds

National Science Foundation

Through the Convergence Accelerator program of the Directorate for Technology, Innovation and Partnerships (TIP), support was provided to the University of North Carolina Wilmington for "Accelerating commercial marine fish production in the US: Developing sustainable feeds, establishing feed suppliers and enhancing market acceptance."

Objective 2.4: Improve engineering systems for aquaculture

USDA Agricultural Research Service

Precision aquaculture technologies for recirculating systems. Although precision agriculture technologies have not been widely applied to U.S. aquaculture, they could eliminate fish stress associated with the traditional, hands-on methods for estimating population biomass. ARS-funded scientists in Shepherdstown, West Virginia developed an artificial intelligence (AI)-aided computer vision system for real-time fish monitoring of fish size and numbers in recirculating aquaculture systems. Underwater images and videos were acquired to train an AI fish detection model and the developed vision system detected whole and partial fish in the field of view with more than 85 percent precision. These findings demonstrate the capability for precision technology to assist non-invasive fish condition monitoring and biomass estimation, benefiting fish health, welfare, and production efficiency.

USDA National Institute of Food and Agriculture

Provided support to the University of Hawaii for the integration of nanobubbles in aquaculture and aquaponic systems.

Provided support to the University of New Hampshire for the optimization of aquaponics production using an integrated systems approach.

Provided support to the University of Texas, Rio Grande Valley to advance freshwater prawn production by solving the national problem of prawn postlarvae availability through engineering and automation.

Provided support to North Carolina State University for the development of a customizable fleet of autonomous co-robots for advancing aquaculture production.

Provided support to Virginia Polytechnic Institute and State University to develop Ocean-powered robots for autonomous offshore aquaculture.

Provided support to Florida Atlantic University for the development of hybrid aerial/underwater robotic systems for scalable, adaptable maintenance of aquaculture fish farms.

Provided support to the University of Hawaii to adapt precision farming technologies for sustainable aquaponics systems in Hawaii.

Provided support to the University of Maryland for sustainable aquaculture systems supporting Atlantic salmon (SAS2).

Provided support to Triple N Oyster Farm for inland production of oyster seed utilizing an artificial seawater closed recirculating aquaculture system.

Provided support to Springtide Seaweed for the development of seaweed farming systems for new Nori and Dulse aquaculture crops.

Provided support to AI Control Technologies for the development of novel aquaculture operations

management and control systems.

Provided support to Blue Dot Sea Farms for development of novel carbon fiber long-lines for sustainable multi-species aquaculture.

Provided support to the University of New Hampshire for improvement of finfish production in recirculating systems.

Provided support to North Carolina State University to improve productivity and sustainability of coastal aquaculture via smart engineering.

US Geological Survey

Winged Mapleleaf (*Quardula fragosa*) Propagation to Help Save Endangered Species. Propagation and restoration efforts for two federally endangered unionid mussels, Higgins' Eye and Winged Mapleleaf have continued in the St. Croix National Scenic Riverway (SACN) since about 2000. Propagation methods developed for Higgins' Eye enabled captive-reared subadult mussels to be reintroduced into rehabilitated habitats in the upper Mississippi River Basin and several tributaries, including the SACN. Propagation efforts for the Winged Mapleleaf have had less success, except for a single event in 2005. Currently, there are only five known populations of Winged Mapleleaf, one in the northern US and four in the south. The northern population is limited to a 17-mile stretch of the SACN and is estimated to be ~13,000 Winged Mapleleaf. The SACN population is valuable because (1) it is physically isolated and genetically distinct from southern population and (2) is the only known self-sustaining population within the upper Mississippi River Basin. The significant range reductions of the Winged Mapleleaf and the threat of the zebra mussel to the northern population led an interagency team to develop and implement a plan is to reestablish the northern population of Winged Mapleleaf within its historic range.

Native freshwater mussels have a complex reproductive cycle which includes a parasitic larval stage (glochidia) that for most species requires species-specific fish hosts. Channel Catfish are the only known host for Winged Mapleleaf in the SACN and glochidia are assumed to overwinter on host catfish and detach the following spring. Propagation success for Winged Mapleleaf has been limited from high mortality of infested host fish over wintering in a hatchery or in cages in SACN and high mortality of newly transformed juvenile Winged Mapleleaf held in the laboratory. Our research is helping to understand how to improve overwintering fish host survival and how the health of the host fish and other factors can support propagation efforts. We are also exploring field and laboratory propagation techniques to optimize survival and growth of juvenile Winged Mapleleaf. In 2021, one hundred Channel Catfish were infested with glochidia from three female Winged Mapleleaf and overwintered in outdoor earthen ponds at UMESC. The following spring is effort produced ~58,000 juveniles. Approximately 3,600 juveniles were placed into a USGS bioassay trailer positioned along the SACN in early June. USGS and partners recovered 102 live juvenile mussels that had grown from about 0.3 mm to 4 mm total length by mid-September. Those mussels are being held in a rearing tote in the SACN near Hudson, WI and are the first propagated Winged Mapleleaf to overwinter in the SACN since 2005. USGS and partners will continue to work collaboratively to refine propagation holding techniques to increase juvenile Winged Mapleleaf survival and growth. https://doi.org/10.4003/006.030.0104; https://doi.org/10.1674/0003-0031(2007)157[297:TCFELS]2.0.CO;2

Effects of formaldehyde (Parasite-S®) on biofilter nitrification from a cold- and a warm freshwater RAS. The effect of Parasite-S® (an aqueous formaldehyde solution) on the nitrification processes of biofilters was evaluated in two recirculating aquaculture systems (RASs). Rearing tanks in the warmwater RAS contained yellow perch (*Perca flavescens*) and grass carp (*Ctenopharyngodon idella*) with an initial weight of 166.8 kg and a mean density of 39.5 kg/m3. Rearing tanks in the coldwater RAS contained rainbow trout (Oncorhynchus mykiss) and lake trout (Salvelinus namaycush) with an initial weight of 1377.8 kg at a system density of 41.9 kg/m3. Parasite-S® was administered to the entire system on four consecutive days in both trials to achieve a nominal concentration of 14.8 mg/L formaldehyde (40 mg/L formalin) at the biofilter. Removal efficiencies for total ammonia nitrogen (TAN) and nitrite nitrogen were measured as indicators of biofilter nitrification processes. The active ingredient in Parasite-S®, formaldehyde, was measured until it was below the method detection limit of 0.8 mg/L. TAN volumetric removal rate was significantly decreased in both systems after formaldehyde addition and remained below pre-exposure efficiency in the coldwater RAS. Nitrite nitrogen volumetric removal rate was not significantly different, but the slope and intercepts were less after formaldehyde addition indicating an effect on the nitrifying bacteria. Although removal rates were decreased, no mortality occurred after four consecutive formaldehyde indefinite bath exposures in either system. https://doi.org/10.1111/are.16046

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following project involves conducting engineering research:

- Continuation of Aquaculture Hub: Building Capacity of Land-Based Atlantic Salmon Aquaculture in the U.S.

Via the FY22 competition "Early Stage Propagation Strategies for Aquaculture Species," of the 9 projects funded, the following project involves conducting engineering research:

- Universal Hatchery System for Developing New Seaweed Strains for Land-Based Aquaculture Production

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including engineering research:

- Pilot Program in which Engineering Students and Aquaculture Practitioners are Brought Together to Create Solutions to Problems that Require Robotic Physical Intervention (MITSG)
- Integration of Alternative Energy and Backup Systems for the Implementation of Land Based Recirculating Aquaculture Systems (RAS) in the US Caribbean (PRSG)

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects including engineering research:

- Designs in infrastructure and best management practices to improve alternative oyster culture farming in response to threats from extreme weather events (LASG)
- Pervasive monitoring of offshore aquaculture installations using moored profilers (MITSG)
- 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 (NHSG)

- Oystermaran II: autonomous surface vehicles for maintenance and intervention in aquaculture farming to improve occupational health and safety (MITSG)

NOAA National Marine Fisheries Service

Supported the following aquaculture engineering research project through the FY22 Interstate Commissions Pilot Project grant program:

- Advancing the viability of oil rig associated aquaculture

Supported the following aquaculture engineering research project through the FY21 Saltonstall-Kennedy grant program:

- Alabama Off Bottom Oyster Wet Storage and Depuration Facility Pilot Project Using Vacuum Air Lift (VAL) Technology

Supported the following aquaculture engineering research project at the NMFS Northeast Fisheries Science Center:

- 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

DOE Water Power Technologies Office

Via FY22 funding opportunities for DOE National Laboratories, the following projects were selected or received continued funding to assess the feasibility of integrating marine energy with marine aquaculture operations:

- Partnership with the Jamestown S'Klallam Tribe to assess the feasibility of using marine energy to help power community-scale shellfish aquaculture and potential future finfish aquaculture in the Salish Sea (Pacific Northwest National Laboratory)
- Assessment of whether a proposed Guam Aquaculture Innovation Center could be powered by ocean thermal energy conversion or wave energy, as well as an assessment of potential environmental impacts, economic factors, and infrastructure needs (Pacific Northwest National Laboratory, Sandia National Laboratories, University of Guam)
- Assessment of the potential to co-locate and power an offshore fish farm with an ocean thermal energy conversion facility in the Gulf of Mexico, Florida Straits, Puerto Rico Trench, and the U.S. Virgin Islands (Argonne National Laboratory, Florida Atlantic University, Gulfstream Aquaculture, and Pinkerton Computer Consultants)Testing a tidal energy device prototype specifically suited for low velocity currents to understand its potential to power coastal kelp or oyster farms (Pacific Northwest National Laboratory)
- Adapting Lab-on-a-Fish (LOAF) biosensor technology, which monitors and transmits data on fish physiology, behavior, and environmental variables, for aquaculture applications by updating hardware and firmware (Pacific Northwest National Laboratory)
- Partnership with Manna Fish Farms to understand the feasibility of co-locating a wave energy device with offshore multi-trophic aquaculture off the coast of Puerto Rico (Pacific Northwest National Laboratory)

Via the Small Business Innovation Research program, the following project was selected in FY22:

- A Novel Wave Energy Converter to Power Offshore Macroalgae (C.A. Goudey & Associates)

National Science Foundation

A Small Business Innovation Research Program (SBIR Phase II) award through June 2023 was made to Minnowtech, LLC: "Sonar Arrays for Maximizing Aquaculture Yields." The project supports the development of technology that provides standardized real-time estimates of shrimp biomass and behavior in aquaculture systems, and will improve financial security for shrimp farmers, ensure food security, and reduce pressure on wild stocks.

Through the Convergence Accelerator program of the Directorate for Technology, Innovation and Partnerships (TIP), support was provided to the University of Maryland College Park, through September 2023, for the Blue Economy Track project, "Convergence Towards Nationwide Smart Precision Aquaculture Networks for Sustainable Shellfish Farming." The project establishes a framework using revolutionary concepts empowered by advanced technologies (e.g., Internet of Things, robotics, and artificial intelligence), scientific discoveries in biology, environmental science, and ocean sciences, and stakeholder-driven economic development, leading to better farm management, economic optimization, and better coping with climate change, and thus enhance production and sustainability in US shellfish aquaculture.

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/https://health.gov/dietaryguidelines/2015/guidelines/ accessed November 17, 2021

[6] One Health, World Health Organization, https://www.who.int/features/qa/one-health/en/, accessed July 13, 2019

[7] https://www.cdc.gov/onehealth/index.html

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

USDA Agricultural Research Service

New strategy for controlling snails. Trematode infestations on catfish farms have been linked to significant production losses and farm closures. Initially recognized as an emerging pest in the late 1990s, management strategies targeted the trematode life cycle by eradicating the snail intermediate host in the pond environment. Copper sulfate is the most widely used treatment option and is highly effective against snails with a single application of 3 ppm, but this treatment level can result in increased mortality in fish, especially when water temperatures are elevated. ARS researchers in Stoneville, Mississippi and Mississippi State University researchers demonstrated that weekly low-dose copper treatments (1.0-1.5 ppm) spread across 4 weeks are as effective in killing snails and treatment rates <0.1 ppm can halt snail reproduction and kill snail embryos. This approach is being combined with a new delivery system to better manage snail populations and reduce trematode populations in catfish ponds. The system utilizes a radar groundspeed sensor and a logic-based control system to distribute granular copper sulfate evenly and accurately along the pond margins in a single pass.

Development of an effective oral enteric septicemia of catfish vaccination platform. Enteric septicemia of catfish is considered the most problematic bacterial disease affecting catfish fingerling production. Historically, management strategies relied on treatment of disease with antimicrobials in medicated feed and feed restrictions to limit the oral route of infection. To develop more proactive management strategies, ARS researchers in Stoneville, Mississippi, developed a live attenuated vaccine along with a mechanized delivery system enabling in-pond vaccination during the early stages of fingerling production. The oral vaccine is currently available by veterinarian prescription and has dramatically increased survival and profitability of fingerling catfish production. Currently, more than 90 percent of catfish produced in Mississippi and Alabama are vaccinated with the delivery platform, which is applicable to other live attenuated vaccines as well. The vaccine also provides cross protection against *Edwardsiella piscicida*, an emerging pathogen in hybrid catfish production.

Detection of a biomarker for bacterial cold-water disease. Fish farmers need rapid methods to assess the health and disease status of their fish. ARS researchers in Leetown, West Virginia and St. George's University collaborators identified a novel serum biomarker that can distinguish between healthy and diseased fish. The biomarker was increased more than 20-fold in the plasma of fish bred for susceptibility to bacterial cold-water disease when exposed to the causative pathogen *Flavobacterium psychrophilum*. An assay was developed and commercialized that can be completed in under 1 hour, providing a commercially available, rapid method for monitoring population health of rainbow trout and Atlantic salmon during grow-out.

Striped bass are highly susceptible to common aquaculture diseases. ARS researchers established the susceptibility of hybrid striped bass (HSB) and their parental species—white bass (WB) and striped bass (SB)—to the most common aquaculture diseases identified by the HSB industry, including columnaris disease, motile aeromonad septicemia, and streptococcosis. Following challenge, only 1% of SB survived the three diseases and died twice as early as WB and HSB. These results established that WB are the most resistant to all three diseases, SB are most susceptible, and HSB are intermediate to the two parental species. ARS is currently working with North Carolina State University (NCSU) partners

to incorporate these results into the ARS – NCSU HSB Selective Breeding Program to incorporate SB disease resistance as a selection trait for potential improvement of HSB disease resistance.

USDA National Institute of Food and Agriculture

Provided support to Mississippi State University to develop targeted management approaches for Channel Catfish Virus in catfish aquaculture.

Provided support to the University of Rhode Island to investigate molecular mechanisms of interspecies interactions in mitigating aquaculture diseases.

Provided support to the University of Pennsylvania to investigate the induction of immune responses in newly found semi-organized lymphoid structures of teleost fish.

Provided support to the University of Connecticut for evaluation of selection for Acute Hepatopancreatic Necrosis Disease survival and resistance in Pacific white shrimp by genome-wide association.

Provided support to Texas A&M University to investigate the impact of dietary glutamate on the development of gut mucosal immunity in hybrid striped bass.

Provided support to the University of Arkansas at Pine Bluff for an investigation of phage endolysins as alternatives to conventional antimicrobials for *Streptococcus iniae*.

Provided support to the University of Maine for the development of cellulose nanomaterials as a novel adjuvant and delivery system for aquatic vaccines.

Provided support to the University of New Mexico to investigate the role of organized nasopharynx associated lymphoid tissues to rainbow trout immune responses to vaccination.

Provided support to Texas State University to elucidate the role of metal cell biology of *Saprolegnia parasitica*.

Provided support to Mississippi State University to evaluate the effectiveness of trans-cinnamaldehyde to control and prevent enteric septicemia of catfish.

Provided support to Mississippi State University to elucidate virulence associated proteins encoded by *Flavobacterium columnare*.

Provided support to the University of Pennsylvania to discover novel IgT-inducing immunobiotics and their protective effects against fish mucosal pathogens.

Provided support to Mississippi State University to study the effect of Microcystin LR exposure on the susceptibility of channel catfish to microbial diseases.

Provided support to Mississippi State University to investigate the role of direct binding of non-specific cytotoxic cells (NCCs) to bacteria as an important innate immune mechanism in catfish.

Provided support to the University of Arizona to develop a viral vector for an oral delivery of RNAi-based therapeutics in shrimp.

Provided support to Louisiana State University to investigate *Edwardsiella ictaluri* pathogenesis.

Provided support to Auburn University to study growth carcass traits and disease resistance of myostatin gene-edited channel catfish and hybrid catfish.

Provided support to the University of California at Davis to study viable protozoan pathogen dynamics in oysters and associated risk to shellfish consumers.

Provided support to the University of California at Davis for the development of a systematic and integrated approach to mitigation of antimicrobial resistance in aquaculture.

Provided support to Mississippi State University to study the transfer and persistence of multi-drug resistance plasmids in the intestinal microbiota of catfish.

Provided support to the University of Mississippi Medical Center to identify Toll-like receptor ligands in channel catfish.

Provided support to Mississippi State University to develop a dual live attenuated vaccine to prevent motile Aeromonas septicemia and enteric septicemia of catfish.

Provided support to Mississippi State University to identify the role of the tight adherence operon Genes of epidemic *Aeromonas hydrophila*-caused disease in channel catfish and use to develop vaccines.

Provided support to Auburn University to study the effect of gene editing of reproductive genes on fertility, growth, disease resistance and body composition of transgenic catfish.

Provided support to Delaware State University to establish a PHAGE and new omics capacity for the mitigation of AMR bacteria.

Provided support to Varigen Biosciences Corporation to develop a simple and easy to use diagnostic assay for rapid detection of virulent strains of *Aeromonas hydrophila* (vAh).

Provided support to NuLode LLC. to investigate Oral vaccine delivery for control of Tilapia Lake Virus (TiLV).

Provided support to Michigan State University to evaluate vertical transmission cycles of virulent *Flavobacterium psychrophilum* sero-/genotypes.

Provided support to the University of California at Davis to study the impact of OsHV-1 Microvariants on *Crassostrea virginica* family lines.

Provided support to Auburn University for the rapid validation of immunogenic targets from hypervirulent *Aeromonas hydrophila* for development of a recombinant protein vaccine against vMAS in channel catfish (*Ictalurus punctatus*).

Provided support to the University of Arizona to develop PCR-based diagnostic assays in support of disease-free attestations of formulated aquafeed.

Provided support to the University of Idaho to evaluate the efficacy and immunomodulatory property of probiotic C6-6 for early life stage management of coldwater and columnaris disease and coinfection.

Provided support to Mississippi State University to investigate management of fish-borne trematodes in pond-raised Ictalurid catfish.

Provided support to Texas State University to develop nasal and gut probiotics to protect intensive catfish culture against *Edwardsiella ictaluri* infections.

Provided support to Auburn University to explore and exploit host-pathogen interactions for disease prevention in warmwater aquaculture.

Provided support to the University of Maine to advance lumpfish aquaculture and their use as biological delousers in salmonid ocean farms.

Provided support to the University of Maine to prevent invasive fungal disease in fish.

Provided support to the University of Arizona to investigate acute hepatopancreatic necrosis disease (AHPND) and hepatopancreatic microsporidiosis (HPM) in Pacific white shrimp.

Provided support to the University of New Hampshire to study ecosystem variation and pathogenic *Vibrio parahaemolyticus* population dynamics in estuarine shellfish.

Provided support the University of Arkansas at Pine Bluff to investigate Syzygium-CS/TPP Nanoparticles, a potential prophylactic and therapeutic for *Aeromonas hydrophila* infections in fish.

FDA Center for Veterinary Medicine (CVM)

The FDA withdrew guidance for industry (GFI) #210, "The Index of Legally Marketed Unapproved New Animal Drugs for Minor Species" to revise it in accordance with a statutory change to the wording of required label statements and because the guidance no longer represents the agency's current thinking. A revised draft guidance will be published as expeditiously as possible. The FDA received feedback regarding guidance #210 in response to a request for information in June 2021 asking for stakeholder feedback on expanding eligibility for indexing for certain groups of animals from food-producing species when there is reasonable certainty that those animals would not enter the food supply. The vast majority of comments received support the contention that there is a "reasonable certainty" that certain subsets of minor species generally considered to be food-producing animals will not be used as food for humans or food-producing animals, including laboratory rabbits and broodstock fish. While the guidance is being revised, FDA's Office of Minor Use and Minor Species Animal Drug Development (OMUMS) will determine the eligibility of a drug for indexing on a case-by-case basis.

The FDA Minor Use Minor Species Grant Program made two awards for aquaculture projects this year. The grant recipients were AQUI-S New Zealand for an oral (gavage) two-generation reproductive toxicity study of eugenol in rats to support the human food safety evaluation of the use of eugenol in fish, and Cornell University to study the safety of AQUAFLOR (50% florfenicol; Type A Medicated Article) administered in feed to marine finfish species.

New interpretive criteria to determine antimicrobial resistance among two important bacterial pathogens of fish. The susceptibility of bacterial pathogens of fish to antimicrobial drugs can be tested *in vitro* using similar methods to those used for bacteria from humans and terrestrial animals. However, many of these fish pathogens have unique temperature and nutritional requirements that require specialized adaptations. The Clinical and Laboratory Standards Institute has such standardized testing methods for many bacterial fish pathogens but for most of these pathogens it remains unclear how to interpret the susceptibility data. To address this data gap, CVM scientists collaborated with scientists at the Louisiana State University, Mississippi State University, and Ghent University on two multi-laboratory studies that set criteria to interpret if the pathogens *Aeromonas hydrophila* and *Flavobacterium columnare* have developed resistance against certain antimicrobial drugs. With these criteria, fish health professionals and microbiologists will be able to better detect emerging antimicrobial resistance in aquaculture settings. Lastly, veterinarians confronted with disease events caused by these pathogens will have improved data as they strive to use approved antimicrobials in a judicious fashion.

Development of tools to monitor seafood safety. FDA and USDA collaborate on a technical advisory group to coordinate the development and validation of chemical detection methods to ensure the safety of seafood sold in the United States. NOAA also participates in the advisory group meetings.

US Geological Survey

Exploration of the 2016 Yellowstone River fish kill and proliferative kidney disease in wild fish populations. Proliferative kidney disease (PKD) is an emerging disease that recently resulted in a large mortality event of salmonids in the Yellowstone River (Montana, USA). Total PKD fish mortalities in the Yellowstone River were estimated in the tens of thousands, which resulted in a multi-week river closure and an estimated economic loss of US$500,000. This event shocked scientists, managers, and the public, as this was the first occurrence of the disease in the Yellowstone River, the only reported occurrence of the disease in Montana in the past 25 yr, and arguably the largest wild PKD fish kill in the world. To understand why the Yellowstone River fish kill occurred, we used molecular and historical data to evaluate evidence for several hypotheses: Was the causative parasite *Tetracapsuloides bryosalmonae* a novel invader, was the fish kill associated with a unique parasite strain, and/or was the outbreak caused by unprecedented environmental conditions? We found that *T. bryosalmonae* is widely distributed in Montana and have documented occurrence of this parasite in archived fish collected in the Yellowstone River prior to the fish kill. *T. bryosalmonae* had minimal phylogeographic population structure, as the DNA of parasites sampled from the Yellowstone River and distant water bodies were very similar. These results suggest that *T. bryosalmonae* could be endemic in Montana. Due to data limitations, we could not reject the hypothesis that the fish kill was caused by a novel and more virulent genetic strain of the parasite. Finally, we found that single-year environmental conditions are insufficient to explain the cause of the 2016 Yellowstone River PKD

outbreak. Other regional rivers where we documented *T. bryosalmonae* had similar or even more extreme conditions than the Yellowstone River and similar or more extreme conditions have occurred in the Yellowstone River in the recent past, yet mass PKD mortalities have not been documented in either instance. We conclude by placing these results and unresolved hypotheses into the broader context of international research on *T. bryosalmonae* and PKD, which strongly suggests that a better understanding of bryozoans, the primary host of *T. bryosalmonae*, is required for better ecosystem understanding. https://doi.org/10.1002/ecs2.3436

A probe-based quantitative PCR assay for detecting *Tetracapsuloides bryosalmonae* in fish tissue and environmental DNA water samples. A probe-based quantitative real-time PCR assay was developed to detect *Tetracapsuloides bryosalmonae*, which causes proliferative kidney disease in salmonid fish, in kidney tissue and environmental DNA (eDNA) water samples. The limits of detection and quantification were 7 and 100 DNA copies for calibration standards and *T. bryosalmonae* was reliably detected down to 100 copies in tissue and eDNA samples. The assay presented here is a highly sensitive and quantitative tool for detecting *T. bryosalmonae* with potential applications for tissue diagnostics and environmental detection. https://doi.org/10.1007/s12686-017-0812-3

Improved Conventional PCR Assay for Detecting *Tetracapsuloides bryosalmonae* DNA in Fish Tissues. Conventional PCR is an established method to detect *Tetracapsuloides bryosalmonae* DNA in fish tissues and to confirm diagnosis of proliferative kidney disease (PKD) caused by *T. bryosalmonae*. However, the commonly used PKX5f-6r primers were designed with the intention of obtaining sequence information and are suboptimal for determining parasite DNA presence. A new PCR assay to detect *T. bryosalmonae* 18s rDNA, PKX18s1266f-1426r, is presented that demonstrates specificity, repeatability, and enhanced sensitivity over the PKX5f-6r assay. The limit of detection of the PKX18s1266f-1426r assay at 95% confidence was 100 template copies, and the new primers detected parasite DNA more consistently at template concentrations below 100 copies than did PKX5f-6r. The PKX18s1266f-1426r also achieved 100% detection at sample DNA concentrations one order of magnitude lower than PKX5f-6r. Out of 127 salmonid fish with unknown *T. bryosalmonae* infection status, PKX5f-6r detected 35 positive samples, while the new assay detected 43. The discrepancy in *T. bryosalmonae* detection between the two primer sets may be attributed to several differences between the assays, including oligonucleotide melting temperatures, the use of a touchdown PCR thermal cycle, and amplicon length. https://doi.org/10.1002/aah.10020

Evaluation of *Francisella orientalis* ΔpdpA as a live attenuated vaccine against piscine Francisellosis in Nile tilapia. *Francisella orientalis* is an important bacterial pathogen of marine and freshwater fish with worldwide distribution. Fish francisellosis is a severe subacute to chronic granulomatous disease, with high mortalities and high infectivity rates in cultured and wild fish. To date, there is no approved vaccine for this disease. In this study, we evaluated the efficacy of a defined *F. orientalis* pathogenicity determinant protein A (pdpA) mutant (ΔpdpA) as a live attenuated immersion vaccine against subsequent immersion challenge with the wild-type organism. Immunized Nile tilapia *Oreochromis niloticus* were protected (45% relative percent survival) from the lethal challenges and presented significantly lower mortality than nonvaccinated and challenged treatments. Although serum IgM was significantly higher in immunized fish, similar bacterial loads were detected in vaccinated and nonvaccinated survivors. In conclusion, although the *F. orientalis* ΔpdpA is attenuated and effectively stimulated an adaptive immune response, the low relative percent survival and high bacterial persistence in survivors of immunized and challenged treatments indicates low suitability of

ΔpdpA as a mucosal vaccine for tilapia under conditions used in this study. https://doi.org/10.1002/aah.10166

Rapid diagnostic test to detect and discriminate infectious hematopoietic necrosis virus (IHNV) genogroups U and M to aid management of Pacific Northwest salmonid populations. Infectious hematopoietic necrosis virus (IHNV) is an acute pathogen of salmonids in North America, Europe, and Asia that is phylogenetically classified into five major virus genogroups (U, M, L, E, and J). The geographic range of the U and M genogroup isolates overlap in the North American Columbia River Basin and Washington Coast region, where these genogroups pose different risks depending on the species of Pacific salmon (*Oncorhynchus* spp.). For certain management decisions, there is a need to both test for IHNV presence and rapidly determine the genogroup. Herein, we report the development and validation of a U/M multiplex reverse transcription, real-time PCR (RT-rPCR) assay targeting the IHNV nucleocapsid (N) protein gene. The new U/M RT-rPCR is a rapid, sensitive, and repeatable assay capable of specifically discriminating between North American U and M genogroup IHNV isolates. However, one M genogroup isolate obtained from commercially cultured Idaho rainbow trout (*O. mykiss*) showed reduced sensitivity with the RT-rPCR test, suggesting caution may be warranted before applying RT-rPCR as the sole surveillance test in areas associated with the Idaho trout industry. The new U/M assay had high diagnostic sensitivity (DSe > 94%) and specificity (DSp > 97%) in free-ranging adult Pacific salmon, when assessed relative to cell culture, the widely accepted reference standard, as well as the previously validated universal N RT-rPCR test. The high diagnostic performance of the new U/M assay indicates the test is suitable for surveillance, diagnosis, and confirmation of IHNV in Pacific salmon from the Pacific Northwest regions where the U and M genogroups overlap. https://doi.org/10.3390/ani12141761

Loop-mediated isothermal amplification (LAMP) assay for detection of Asian fish tapeworm, *Schyzocotyle acheilognathi* (Yamaguti, 1934) [syn. *Bothriocephalus acheilognathi*]. The Asian fish tapeworm (*Schyzocotyle acheilognathi* syn. *Bothriocephalus acheilognathi*) (AFT) is an invasive parasite that can infect many species of fish, although most hosts are primarily members of Cyprinidae. Pathogenicity has most often been reported in aquaculture settings in fry and fingerling stages of carp (*Cyprinus* spp.). More recently, it has been shown to cause growth retardation in the endangered bonytail chub (*Gila elegans*) and found to be widespread in populations of endangered humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. AFT spreads most often through the transport of infected fish, particularly baitfish. Despite its harmful potential, there is no efficient or accurate ante mortem test to detect AFT in water or fish samples before transport. We report on the development of a sensitive and specific loop-mediated isothermal amplification (LAMP) assay to detect the parasite in under 30 minutes from laboratory prepared samples. Six LAMP primers were designed to amplify a variable region of the 18S ribosomal RNA gene in AFT with the detection and quantification of DNA on a real-time fluorometer. The limit of detection was 1 × 101 copies/µl of DNA extracted from as few as 2 AFT eggs. Future application of our assay would be a low-cost test to rapidly and accurately detect AFT DNA from environmental samples on-site so that preventive actions can be taken to halt the spread of the AFT through the movement of infected fish. https://doi.org/10.1645/21-56

Herring Disease Program - Annual Project Report 2012011-E, February 1, 2010-January 31, 2021. We will investigate fish health factors that may be contributing to the failed recovery of Pacific herring populations in Prince William Sound. Field samples will provide infection and disease prevalence data from Prince William Sound and Sitka Sound to inform the age structured assessment (ASA) model,

serological data will indicate the prior exposure history and future susceptibility of herring to viral hemorrhagic septicemia virus (VHSV), and diet information will provide insights into the unusually high prevalence of *Ichthyophonus* that occurs in juvenile herring from Cordova Harbor. Laboratory studies will validate the newly developed plaque neutralization assay as a quantifiable measure of herd immunity against VHS, provide further understanding of disease cofactors including salinity, and investigate possible routes of transmission for *Ichthyophonus*. Information from the field and laboratory studies will be integrated into the current ASA model and inform a novel ASA-type model that is based on the immune status of herring age cohorts. *https://pubs.er.usgs.gov/publication/70222411*

Evidence for the use of mucus swabs to detect *Renibacterium salmoninarum* in brook trout. Efforts to advance fish health diagnostics have been highlighted in many studies to improve the detection of pathogens in aquaculture facilities and wild fish populations. Typically, the detection of a pathogen has required sacrificing fish; however, many hatcheries have valuable and sometimes irreplaceable broodstocks, and lethal sampling is undesirable. Therefore, the development of non-lethal detection methods is a high priority. The goal of our study was to compare non-lethal sampling methods with standardized lethal kidney tissue sampling that is used to detect *Renibacterium salmoninarum* infections in salmonids. We collected anal, buccal, and mucus swabs (non-lethal qPCR) and kidney tissue samples (lethal DFAT) from 72 adult brook trout (*Salvelinus fontinalis*) reared at the Colorado Parks and Wildlife Pitkin Brood Unit and tested each sample to assess *R. salmoninarum* infections. Standard kidney tissue detected *R. salmoninarum* 1.59 times more often than mucus swabs, compared to 10.43 and 13.16 times more often than buccal or anal swabs, respectively, indicating mucus swabs were the most effective and may be a useful non-lethal method. Our study highlights the potential of non-lethal mucus swabs to sample for *R. salmoninarum* and suggests future studies are needed to refine this technique for use in aquaculture facilities and wild populations of inland salmonids. https://doi.org/10.3390/pathogens10040460

Analytical validation of two RT-qPCR tests and detection of spring viremia of carp virus (SVCV) in persistently infected koi *Cyprinus carpio*. Spring viremia of carp virus (SVCV) ia a carp sprivivirus and a member of the genus *Sprivivirus* within the family Rhabdoviridae. The virus is the etiological agent of spring viremia of carp, a disease of cyprinid species including koi *Cyprinus carpio L.* and notifiable to the World Organisation for Animal Health. The goal of this study was to explore hypotheses regarding inter-genogroup (Ia to Id) SVCV infection dynamics in juvenile koi and contemporaneously create new reverse-transcription quantitative PCR (RT-qPCR) assays and validate their analytical sensitivity, specificity (ASp) and repeatability for diagnostic detection of SVCV. RT-qPCR diagnostic tests targeting the SVCV nucleoprotein (Q2N) or glycoprotein (Q1G) nucleotides were pan-specific for isolates typed to SVCV genogroups Ia to Id. The Q2N test had broader ASp than Q1G because Q1G did not detect SVCV isolate 20120450 and Q2N displayed occasional detection of pike fry sprivivirus isolate V76. Neither test cross-reacted with other rhabdoviruses, infectious pancreatic necrosis virus or co-localizing cyprinid herpesvirus 3. Both tests were sensitive with observed 50% limits of detection of 3 plasmid copies and high repeatability. Test analysis of koi immersed in SVCV showed that the virus could be detected for at least 167 d following exposure and that titer, prevalence, replicative rate and persistence in koi were correlated significantly with virus virulence. In this context, high virulence SVCV isolates were more prevalent, reached higher titers quicker and persisted in koi for longer periods of time relative to moderate and low virulence isolates. https://doi.org/10.3354/dao03564

Comparative susceptibilities of selected California Chinook salmon and steelhead populations to isolates of L Genogroup Infectious Hematopoietic Necrosis Virus (IHNV). Salmonid species demonstrate varied susceptibility to the viral pathogen infectious hematopoietic necrosis virus (IHNV). In California conservation hatcheries, juvenile Chinook salmon (*Oncorhynchus tshawytscha*) have experienced disease outbreaks due to L genogroup IHNV since the 1940s, while indigenous steelhead (anadromous *O. mykiss*) appear relatively resistant. To characterize factors contributing to the losses of California salmonid fish due to IHNV, three populations of Chinook salmon and two populations of steelhead native to California watersheds were compared in controlled waterborne challenges with California L genogroup IHNV isolates at viral doses of 104–106 pfu mL−1. Chinook salmon fry were moderately to highly susceptible (CPM = 47–87%) when exposed to subgroup LI and LII IHNV. Susceptibility to mortality decreased with increasing age and also with a higher temperature. Mortality for steelhead fry exposed to two IHNV isolates was low (CPM = 1.3–33%). There was little intraspecies variation in susceptibility among populations of Chinook salmon and no differences in virulence between viruses strains. Viral persistence was demonstrated by the isolation of low levels of infectious IHNV from the skin of two juvenile Chinook salmon at 215 d post exposure. The persistence of the virus among Chinook salmon used for stocking into Lake Oroville may be an explanation for the severe epidemics of IHN at the Feather River hatchery in 1998–2002. https://doi.org/10.3390/ani12131733

US Fish and Wildlife Service

The USFWS Aquatic Animal Drug Approval Partnership (AADAP) continues to work with partners to obtain FDA approval of safe and effective new drugs for use in aquaculture and fisheries management. In fiscal years 2021 and 2022, the USFWS suspended enrollment fees typically required to participate in AADAP's National Investigational New Animal Drug (INAD) Program in appreciation of partner support. This fee waiver financially benefited INAD program participants including other federal agencies, tribes, states, academic, and private entities. In addition, AADAP's research program continues to conduct or assist partners with Effectiveness and Target Animal Safety studies to fulfill data needs for Technical Sections required for drug approvals through the FDA. AADAP worked with the National Aquaculture Association and other partners in providing justification to FDA's Office of Minor Use and Minor Species for expansion of eligibility for indexing drugs to include certain subsets of food-producing minor species, such as broodstock fish, when there is a reasonable certainty that these animals will not be consumed by humans or food-producing animals after receiving an indexed drug.

The USFWS 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, USFWS Fish Health staff provided input to the proposed restructuring of the Bluebook Inspection Standards Committee and Testing Standards Committee. Also in 2022, the full network of USFWS Fish Health Centers achieved Tier 2 AFS laboratory certification.

Other work designed to protect the health of aquaculture species includes USFWS aquatic invasive species (AIS) efforts. The USFWS awarded a grant to Oregon State University to produce an after-action report of the action 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 of 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 September 2023.

NOAA Sea Grant

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following project involves conducting health research:

- Continued Support for Expanding the Atlantic and Gulf Shellfish Seed Biosecurity Collaborative
- West Coast Aquaculture Collaborative

Via the FY22 competition "Early Stage Propagation Strategies for Aquaculture Species," of the 9 projects funded, the following projects involve conducting health research:

- Probiotic-Induced Protection of Oyster Larvae against Bacterial Pathogens that Impact Hatchery Production
- Stress-Priming of Early-Stage Eastern Oysters to Increase Stress Tolerance and Consistency of Aquaculture Production in the Face of Climate Variability

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects including health research:

- Emerging *V. campbellii* and *V. harveyi* Pathogens: Detection Methods and their Validation" (GASG)

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects including engineering research:

- Expanding the Aquaculture Research Capacity at WHOI
- Bacterial Predation: A Solution of Vibrio Control For Oyster Hatcheries? (LASG)
- Against All Odds: Development of Bay Scallop Strains that Resist Temperature and Disease Stress (NYSG)
- CRISPR- Based Portable Biosensor System for On-Site Detection of Fish Pathogens (OHSG)
- Does the Thermal History of the Commercially Farmed Pacific Oyster (Crassostrea gigas) Influence Tolerance to Temperature-Related Disease Outbreaks? (CASG)
- Innovative Biological Control of Vibrio Spp. in Gulf Oyster Hatcheries (LASG)
- Recovery of Louisiana's Iconic Shellfish: Diagnosis and Evaluation of White Spot Syndrome Virus Disease in Crawfish (LASG)
- Low Cost, Autonomous, Real-Time 3D Imaging for Offshore Aquaculture Health Monitoring and Stock Assessment (MITSG)
- Does Breeding Disease-Tolerant Oysters Increase Disease in Coastal Marine Ecosystems? (RISG)
- Virulence Factors and Control of the Fish Pathogen *Flavobacterium columnare* (WISG)

NOAA National Marine Fisheries Service

Supported the following projects focused on aquatic animal health through the FY21 and FY22 Saltonstall-Kennedy grant program:

- A transcriptomic study of the differential stress response between diploid and triploid eastern oyster *Crassostrea virginica*, and its potential involvement in triploid mortality
- Characterizing the role of toxic phytoplankton byproducts in shellfish hatchery failures
- Influence of selective breeding on human pathogenic *Vibrio* spp. in eastern oysters

- Development of Chemosensory-based Control Methods to Reduce the Losses of Commercial Oyster Stocks by Oyster Drills
- Understanding Triploid Pacific Oyster Mortalities on the U.S. West Coast

Supported the following projects focused on aquatic animal health through the FY21 and FY22 Small Business Innovation Research Phase II grant program:

- Rapid diagnostic testing for marine velvet disease, *Amyloodinium ocellatum*: a potential game changer for disease prevention and economic gain for fisheries and aquaculture
- HABSSED: Harmful Algal Bloom Surveillance by Sequencing of Environmental DNA
- Continuous eDNA Monitoring for Early Detection of Aquaculture Diseases
- Rapid, Simple Diagnostic for Pathogens in Marine Aquaculture
- Non-Equilibrium Short-Pulsed Discharge for Removal of Antibiotics and Pathogens from Water used in Aquacultural Facilities

Supported NMFS regional science centers with the following aquaculture projects focused on aquatic animal health:

- Developing monitoring and mitigation strategies for Harmful Algal Blooms on Alaska oyster farms
- 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*
- Advancing Milford Laboratory's probiotic bacterial strain OY15 to commercialization: Laboratory and hatchery-scale trials of bacterial probiotic strain OY15 on larvae of the Pacific oyster (*Crassostrea gigas*)

National Science Foundation

A Small Business Innovation Research Program (SBIR Phase II) award through August 2023 was made to Lucendi, Inc.: "AI-based automated, portable, and high-throughput platform for early identification and characterization of potentially harmful microorganisms in aquaculture." The project supports the development of a cost-effective, high-performance platform to monitor and characterize plankton and other microorganisms in water, such as sea lice and harmful algae, that are detrimental to the wellbeing of aquaculture animals.

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

USDA National Institute of Food and Agriculture

Provided support to Virginia State University for an investigation of food safety compliance of hydroponics and aquaponics production in Virginia, and proof of concept Generally Recognized as Safe (GRAS) intervention against potential risks.

Provided support to a Hatch multistate collaborative project focused on mitigating microbial food safety through risk analysis.

Provided support to Oregon State University to extend food safety training to frontline communicators with seafood processors.

Provided support to Oregon State University for increasing food safety of raw oysters with a simple and rapid post-harvest treatment utilizing probiotics.

Provided support to the University of California at Davis to develop green, reusable, and self-cleanable ICE cubes to reduce temperature abuse in cold chain.

FDA Center for Food Safety and Applied Nutrition (CFSAN)

The FDA and EPA have issued advice regarding eating fish. This advice can help those who might become or are pregnant or breastfeeding as well as parents and caregivers who are feeding children make informed choices when it comes to the types of fish that are nutritious and safe to eat. This advice supports the recommendations of the Dietary Guidelines for Americans.

FDA and Federal Partners Launch Study on the Role of Seafood Consumption in Child Growth and Development. In October 2022, the FDA launched 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.

NOAA Sea Grant

Via FY21 funding through the "Addressing COVID-19 Impacts to Seafood Resources" competition, the following ongoing project includes work to promote safety and nutritional value of aquaculture products:

- Assisting and Supporting the NY Seafood Industry through COVID-19 (NYSG)

Via the FY22 competition "Advanced Aquaculture Collaboratives (Hubs) Continued Support Competition," the following project includes work to promote safety and nutritional value of aquaculture products:

- Nurturing the Successful Growth and Maturation of a Domestic Seaweed Aquaculture Industry: Phase II

Via FY22 Sea Grant Program Aquaculture Supplemental funding, established the following ongoing projects that includes work to promote safety and nutritional value of aquaculture products:

- Identify Communities in Massachusetts who Tend to Consume Seafood at Rates Greater than that of the Average American, but who 1) May not be Engaging Local Producers to Procure what they Consume, and 2) Tend to be Underrepresented in the Local Seafood Industry (MITSG)
- Growing Roots for a Sustainable Seafood Hub in South Central Los Angeles, California (USCSG)

Via FY22 funding through Sea Grant Program competitions, the following ongoing projects include work to promote safety and nutritional value of aquaculture products:

- Exploring Nutrient Utilization by Edible Hawaiian Seaweeds for Parallel Aquaculture Development and Sustainability Applications (HISG)
- Addressing Critical Aquaculture-Marketing-Oriented Applied Research and Outreach (Phase 2) (ILINSG)

NOAA National Marine Fisheries Service

Supported the following research project to promote safety and nutritional value of aquaculture products through the FY22 Saltonstall-Kennedy grant program:

- Influence of selective breeding on human pathogenic *Vibrio* spp. in eastern oysters

Supported the following research projects to promote safety and nutritional value of aquaculture products through the FY22 and FY21 Small Business Innovation Research grant program:

- In Situ and Point of Sale Quantification of Human Pathogens Associated with Aquaculture and Shellfish Farming Using Novel Surface Enhanced Raman Spectroscopy Navigation
- Tide to Table Traceability and Marketing System
- Non-Equilibrium Short-Pulsed Discharge for Removal of Antibiotics and Pathogens from Water used in Aquacultural Facilities

Publications, Technology Transfer and Other Information

USDA ARS Agricultural Research Service

Mechanism	# New
Peer Reviewed Journal Articles	68
Book Chapters, Review Articles, Trade Articles, Popular Press Articles, Database Datasets	8
Material Transfer Research Agreements	4
Material Transfer Agreements	17
New Patent Applications Filed	3
New Patents (patented)	1

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NOAA SeaGrant Publications

Publications in 2022 resulting from NOAA Sea Grant funded projects– please note this list is not yet comprehensive for 2022

Mechanism	# New
Peer Reviewed Journal Articles	9
Book Chapters, Review Articles, Trade Articles, Popular Press Articles, Database Datasets	2
Sea Grant Publications	2

1. Ehrhart, A.L., Doerr, A.N. 2022. Oregon Marine Aquaculture: Barriers, Opportunities and Policy Recommendations [White paper]. Oregon Sea Grant. https://seagrant.oregonstate.edu/files/oregon_marine_aquculture_2022_final_accessible.pdf.
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NOAA National Marine Fisheries Service

Publications in 2021-2022 from NMFS supported research and partnerships. This list should not be considered to be comprehensive.

Mechanism	# New
Peer Reviewed Journal Articles	49
NOAA Technical Memoranda	6
Book Chapters	1
Strategic Plans	2

1. NOAA. 2022. NOAA Aquaculture Strategic Plan (2023-2028). https://media.fisheries.noaa.gov/2022-10/Strategic-Plan-102422-web.pdf
2. NOAA Fisheries. 2022. Alaska Fisheries Science Center Aquaculture Strategic Science Plan. https://media.fisheries.noaa.gov/2022-08/Aquaculture-StrategicSciencePlan-21JUL2022-%5B508%5D.pdf
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