National Program 106 Aquaculture Annual Report for 2022

This report communicates research and technology transfer highlights from ARS scientists and their support staffs working in National Program 106 – Aquaculture from October 1, 2021, through September 30, 2022. Additional information can be found in individual project annual reports located here.

The **vision** for ARS aquaculture research and technology transfer is *to enable science-based use of our natural resources to meet the seafood demands of a growing global population.*

Mission: The mission of National Program (NP) 106, Aquaculture, is to conduct research and deliver technologies that improve domestic aquaculture production efficiency and product quality while minimizing impacts on natural resources.

The aim of the ARS Aquaculture Program is to support a safe and affordable domestic supply of seafood products for 330 million U.S. consumers that is produced in a healthy, competitive, and sustainable aquaculture sector; a sector supported by almost 3000 aquaculture farmers producing more than $1.5 billion farm gate value worth of goods annually. In 2019 the USDA National Agricultural Statistics Service (NASS) published the 2018 Census of Aquaculture updating these statistics for the first time since 2013. The report details many features of aquaculture in the United States, and shows that since 2005, the overall number of farms has dropped (from about 3093 to 2932 from 2013 to 2018). However, farm gate sales in 2018 increased to over $1.51 billion from 2013 level of $1.37 billion.

In fiscal year 2022 the ARS Office of National Programs contributed to many federal aquaculture activities, including:

- Leadership in the National Science and Technology Council (NSTC) Subcommittee on Aquaculture provided by an ARS Co-Chair, Executive Secretary and the Chair of the Science Planning Task Force developing the National Strategic Plan for Aquaculture Research;

- Assistance provided to USDA APHIS towards the development of the National Aquaculture Health Plan and Standards;

- Contributing to Theme Teams led by the USDA Office of the Chief Scientist towards implementing the USDA Science Blueprint: A Roadmap for USDA Science from 2020 to 2025;

- Co-organizing the 2020 49th United States-Japan Natural Resources Aquaculture Workshop, presenting an overview on the Aquaculture Information Exchange partnership between USDA, National Oceanographic Atmospheric Administration (NOAA) and Virginia Tech University;

- Leading an interagency Federal Working Group in response to Congressional Guidance that will explore opportunities for reducing ocean acidification through the farming of seaweeds and seagrasses;

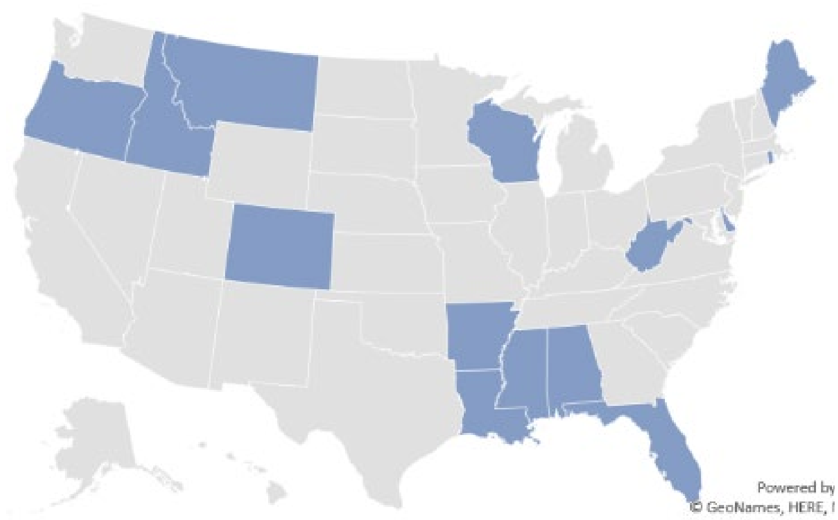
- Representing USDA on the Office of Science and Technology Policy (OSTP) Interagency Council for Advancing Meteorological Services Committee;
- Partnering with NOAA and USDA NIFA to respond to the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries Questionnaire; and
- Engaging with the Bureau of Labor and Statistics regarding inclusion of aquaculture products in the Producer Price Index.

Fiscal year 2022 was the third year of externally-reviewed five-year project plans (2020- 2024) that fall under the six Components of the 2020 – 2024 Aquaculture National Program Action Plan which are:

1. Improving the Efficiency and Sustainability of Catfish Aquaculture;
2. Improving the Efficiency and Sustainability of Salmonid Aquaculture;
3. Improving the Efficiency and Sustainability of Hybrid Striped Bass Aquaculture;
4. Enhancing Shellfish Aquaculture; and
5. Developing Marine Finfish Seedstocks.
6. Developing Sustainable Aquaponic Production Systems

Research themes include genetic improvement, reproduction and development, growth and nutrition, fish health, production systems and product quality.

In 2022 NP106 conducted research at 10 main laboratories on 15 project plans including approximately 65 ARS scientists and University or private cooperators on 15 congressionally mandated agreements. During fiscal year 2022, ARS base funding for aquaculture research was approximately $51M, not including approximately $300K from incoming grants and agreements.



Although project plans guide most of the efforts of the laboratories, we remain flexible to respond to unanticipated challenges and opportunities. NP 106 research covers the spectrum from fundamental to applied research and is focused on solving problems through long term high impact research. The 2020-2024 NP106 Action Plan was approved in 2018 and amended in 2019 and 2021 in response to new funding provided for research in warmwater marine finfish and aquaponics.

2022 NP 106 Technology transfer activities are summarized in **Table 1** below.

Mechanism	# New
Peer Reviewed Journal Articles	68
Material Transfer Research Agreements	4
Material Transfer Agreements	17
New Patent Applications Filed	3
New Patents (patented)	1

NP 106 scientists were also active in serving on committees and as advisors/mentors for undergraduate and post-doctoral students and serving as adjunct/affiliate faculty members as outlined in **Table 2** below.

Advising, Mentorship and Outreach Activities	
Advising and Mentorship	
Students and Post-Docs (ARS and Non-ARS)	17
Mentorships	1
Adjunct or Other Appointments	5
Student Targeted Outreach	
Student related outreach activities - # of activities (Presentations to schools, Science fair participation, Student tours/visits to ARS locations)	5
Student related outreach activities - # of student participants (Presentations to schools, Science fair participation, Student tours/visits to ARS locations)	315
Other Outreach	
Other Outreach Activities - # of activities	8
Other Outreach Activities - # of student participants	422
Other Outreach Activities - # of non-student participants	745

In 2022, NP 106 scientists participated in research collaborations with scientists in the following countries:

CANADA:
- Collaborating with a researcher at Ontario Tech University (OTU) in Ontario, Canada to utilize proteomics to determine physiological differences between selected ARS lines and unselected lines when reared on plant-based feeds.

DENMARK:
- ARS researcher in Stuttgart, Arkansas, continue collaborating with scientists at the Technical University of Denmark in Hirtshals on research designed to provide information on peracetic acid used in aquaculture. Collaboration takes place by phone, email exchanges and formal meetings at conferences over many years.

FRANCE:

- University of Wisconsin-Milwaukee cooperator collaborated with Pasteur Institute, Paris, France to analyze *F. columnare* mutants constructed for virulence against larval zebrafish to expand the significance our work by comparing the effects of mutations on different zebrafish life stages (larval and adult).

GEORGIA:

- The Conservation Fund Freshwater Institute is working closely with the USDA's Foreign Agriculture Service (USDA-FAS) on the project "Improving Disease Management in Georgian Trout Farms". USDA-FAS has been working within the Republic of Georgia in a multi-year program to improve agricultural extension services to foster economic growth and rural employment in the agricultural sector. TCFFI personnel will provide expertise to investigate the cause(s) of fish mortalities, provide recommendations to reduce mortalities, and work with USDA-FAS, local extensionists, and diagnostic laboratories to develop training curricula for on-site disease sampling methods and an effective pathogen surveillance program.

GERMANY:

- An ARS researcher in Stuttgart, Arkansas, continues collaboration with scientists at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin on research designed to study the toxicity/effectiveness of peracetic acid to fish and the effectiveness of this compound to control pathogens on fish. Collaboration takes place by email exchanges, video conferencing, formal meetings at conferences and reciprocal visits to labs over many years.

MALAYSIA:

- ARS scientists in Hagerman, Idaho, and Bozeman, Montana, are collaborating with feed companies and the U.S. Grains council based in Kuala Lumpur, Malaysia, and Ohio Corn Delaware, Ohio. The objective is to investigate and increase incorporation of corn distiller's dried grains with solubles (DDGS), a byproduct of ethanol production, in tilapia feeds to expand use in domestic and Asian tilapia aquaculture market.

NORWAY:

- ARS researchers in Auburn, Alabama, are conducting collaborative research with Benchmark GeneticsNorway AS under a formal agreement. The goal of the research is to determine the feasibility of selectively breeding Nile tilapia for resistance to Streptococcus species and other tilapia pathogens.
- ARS researcher in Stuttgart, Arkansas, continue collaborating with scientists in the Fish Health Department of Nofima (Norweign Institute of Food, Fisheries and Aquaculture Research) in Ås on research designed to establish the importance of the potent disinfectant peracetic acid to the global aquaculture industry. Collaboration takes place by email exchanges, video conferencing andformal meetings at conferences over the last several years
- TCFFI personnel have been collaborating in the CtrlAQUA project, 7-year research initiative by Nofima, funded by the Norwegian Research Council and industry partners. The project aims to make closed-containment aquaculture systems reliable and economically viable through identifying biological solutions for producing Atlantic salmon.
- TCFFI personnel have entered into a collaborative agreement with The Arctic University of Norway (UiT) to contribute RAS expertise and research towards "CandRAS", a 7-year project funded by the Norwegian Research Council. Among other things, the work will involve collaboration on design, execution, evaluation, and reporting of experiments in RAS salmon production, the specific areas of which will be based on challenges identified by RAS salmon producers.

PERU:

- ARS scientists in Aberdeen, Idaho, are collaborating with researchers from the trout company OVAseed and the University of Lima in Lima, Peru, to determine the physiological factors related to improved health and growth for rainbow trout when reared at high elevation, low oxygen conditions.

EUROPEAN UNION:

- TCFFI Research Director joined the advisory panel of iFishIENCi (Intelligent Fish feeding through Integration of Enabling technologies and Circular principles), a European Union Horizon 2020 project involving numerous diverse scientist and industry partners in pursuit of improving aquaculture management and practices through innovation and advanced digital information technology.

GLOBAL SEAFOOD ALLIANCE:

- TCCFI personnel worked with Global Seafood Alliance (GSA) to create a standard for the certification of RAS farms under their Best Aquaculture Practices certification program. Work included organizing and chairing a Technical Committee (TC) with industry representatives, academics, and conservation group representatives, developing the standard framework and text, creating consensus among the TC and GSA staff, and making the draft standard available for public comment.

PERSONNEL

Regrettably, NP106 lost three ARS colleagues in 2022 with the passing of Dr. Lew Smith, Dr. Ken Davis, and Dr. Brian Shepherd.

Dr. Smith attended the University of Maryland, earning a B.S. (1950) in dairy science, and an M.S. (1961) and Ph.D. (1968) in animal science. His 45+ year career with the United States Department of Agriculture began in 1961 and he held positions a scientist, research leader and institute director, before joining the National Program Staff as a national program leader. As director of the Beltsville Agricultural Center, Animal Science Institute (1979-88), Lew determined the direction of future animal and dairy science research at Beltsville. His most recent responsibilities before retiring as a senior national program leader centered on USDA research programs for aquaculture and animal well-being. During his career, Lew (co)authored over 125 scientific reports.

Dr. Davis attended the University of Arkansas in Fayetteville, receiving his B.A. in Natural Science in 1963 and his M.S. in Zoology in 1965. He then attended Louisiana State University in Baton Rouge, Louisiana for his doctoral studies, receiving his Ph.D. in Physiology in 1970. Upon graduation, he joined the faculty at Memphis State University (now the University of Memphis) where he served in various educational capacities until 2001. After a 5-year stint as a Research Physiologist at the Harry K. Dupree Stuttgart National Aquaculture Research Center in Stuttgart, Arkansas, he and his family moved to Cleveland, Mississippi. Dr. Davis served as the Research Leader of the Catfish Genetics Research Unit with USDA/ARS in Stoneville, Mississippi until retiring in 2011. Despite his retirement, he continued to collaborate on research efforts with USDA/ARS until his passing. A vigorous researcher and lover of knowledge, Dr. Davis's career included 19 conference presentations, 21 research grants, 95 invited research presentations, and 95 refereed research publications.

Dr. Shepherd received his B.A. in Zoology from the University of Hawai'i (UH) at Mānoa in 1990, Brian was hired as a Research Assistant for a NSF-funded project on Antarctic and Arctic fish ecology, and was awarded the Antarctic Service Medal by the United States Navy for his work. While in Antarctica, Brian developed his initial interest in fish growth and went on to complete his Ph.D. in 1997 at the UH Hawaiʻi Institute of Marine

Biology (HIMB). He then moved to the University of Connecticut (Storrs) Biotechnology Center, where he served as a USDA Postdoctoral Fellow from 1997 to 1999 and Associate Research Scientist in 2000. From 2000 to 2003, he served as Assistant Professor at the University of Kentucky (Lexington) School of Biological Sciences. Dr. Shepherd started his career with ARS in 2003 as a Research Physiologist at the National Center for Cool and Cold Water Aquaculture in Leetown, West Virginia. In 2005, he relocated to Milwaukee, Wisconsin, as the Lead Scientist responsible for developing the ARS Aquaculture Project at the University of Wisconsin-Milwaukee School of Freshwater Sciences. Dr. Shepherd authored or coauthored more than 50 publications, received more than 60 invitations to present his research at local, national, and international conferences; and was awarded more than $1.4M in competitive research grants. He was especially fond of training and mentoring technicians and students and served as committee member for six M.S. and five Ph.D. students.

New scientists in NP 106 in 2022:

Dr. Jason Abernathy, Research Parasitologist, joined the Aquatic Animal Health Research Unit, Auburn, Alabama.

Ms. Amber Johnston, Biological Science Lab Technician, joined the Aquatic Animal Health Research Unit, Auburn, Alabama.

PROMINENT AWARDS

The following scientists in NP 106 received prominent awards in 2022:

Dr. Benjamin Beck, Dr. Benjamin LaFrentz, Dr. Craig Shoemaker, Auburn, Alabama, received the USDA-ARS, Southeast Area Technology Transfer Award, “One fish, two fish, healthier new fish”, for development of fast-growing Nile tilapia with resistance to economically important bacterial pathogens.

Dr. Keshun Liu, Aberdeen, Idaho received the 2022 Alton E. Bailey Achievement Award from American Oil Chemists Society.

Dr. Keshun Liu, Aberdeen, Idaho received the 2022 Archer Daniel Midlands (ADM) Best Paper Award in protein chemistry and nutrition, by AOCS Proteins and Co-Products Division for a paper “An International Collaborative Study on Trypsin Inhibitor Assay for Legumes, Cereals and Related Products” (Liu et al. 2021, JAOCS, 98:375-390).

Dr. Keshun Liu, Aberdeen, Idaho was selected as a 2022 Fellow of International Academy of Food Science and Technology for outstanding contribution to food science and technology.

RESEARCH RESULTS

The following section summarizes the specific research results addressing objectives in the current National Program Action Plan.

Component 1: IMPROVING THE EFFICIENCY AND SUSTAINABILITY OF CATFISH AQUACULTURE

Problem Statement 1A: Improve Catfish Aquaculture Production Efficiency

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 parts per million, 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.

Relevant Publication:
Peer Reviewed Article: Mischke, C.C., Wise, D.J., Griffin, M.J., Rosser, T.G., Tiwari, A., Rehman, J.U., Ashfaq, M.K., Khan, I.A. 2021. Effects of Multiple, Low-Dose Copper Sulfate Treatments on the Marsh Rams-Horn Snail. North American Journal of Aquaculture. 83:363-371. http://doi.org/10.1002/naaq.10207.

Additional Publications:
Peer Reviewed Article: Aksoy, B., Aksoy, M., Jiang, Z., Beck, B.H. 2022. Novel animal feed binder from soybean hulls -evaluation of binding properties. Animal Feed Science and Technology. 288:115292. https://doi.org/10.1016/j.anifeedsci.2022.115292.

Peer Reviewed Article: Ott, B.D., Torrans, E.L., Allen, P.J. 2022. Design of a Vacuum Degassing Apparatus to Reduce Nitrogen Supersaturation and Maintain Hypoxia in Well-Water. North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10263.

Peer Reviewed Article: Ott, B.D., Torrans, E.L., Griffin, M.J., Allen, P.J. 2022. Quantitative PCR assays to measure the HPI axis neuropeptides corticotropin-releasing factor (CRF) and urotensin I (UI) in channel catfish (Ictalurus punctatus). Aquaculture. 555:738253. https://doi.org/10.1016/j.aquaculture.2022.738253.

Peer Reviewed Article: Dharan, V., Aarattuthodi, S., Khoo, L., Bosworth, B.G. 2022. Establishment and charaterization of a cell line from ictalurid catfish.. Journal of the World Aquaculture Society. 53:620-633. https://doi.org/10.1111/jwas.12869.

Problem Statement 1B: Reduce the Impacts of Disease in Catfish Aquaculture

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 the use of medicated feed and feed restrictions to limit the oral route of infection. While both strategies can be effective, the overuse of medicated feeds results in the development of antibiotic resistance, rendering the medication useless, and feed restrictions severely limit growth. In efforts 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.

Relevant Publication:
Peer Reviewed Article: Lopez-Porras, A., Griffin, M.J., Ware, C., Richardson, B.M., Greenway, T.E., Rosser, T.G., Aarattuthodiyil, S., Wise, D.J. 2022. Cross-protection efficacy of a live-attenuated Edwarsiella ictaluri vaccine against heterologous Edwardsiella piscicida isolates in channel and channel x blue hybrid catfish. Journal of Fish Diseases. https://doi.org/10.1111/jfd.13623.

Zinc: the cheaper, safer alternative to copper for preventing pathogens in aquaculture. Copper has been used as a water treatment to prevent bacterial infections for decades, but the price of copper has risen to $10K per ton and demand has increased. Zinc is a closely related element, but it has a market price of $3K per ton. ARS researchers in Stuttgart, Arkansas, ran a series of toxicity trials with largemouth bass fry to evaluate the possibility of zinc as an alternative to copper as a water decontaminant. Their results indicate that zinc is just as effective as copper in killing fish pathogens, but it is only half as toxic to fish, providing farmers a cheaper, safer treatment for preventing disease outbreaks in aquaculture.

Additional Publications:
Abstract: Lafrentz, B.R., Kralova, S., Burbick, C.R., Alexander, T.L., Phillips, C.W., Giffin, M.J., Waldbieser, G.C., Garcia, J.C., De Alexandre Sebasti, F., Soto, E., Loch, T., Liles, M.R., Snkvik, K.R. 2022. Columnaris disease is caused by Flavobacterium columnare and three newly described Flavobacterium spp [abstract]. Western Fish Disease Workshop, Hood River OR, May 16-20, 2022.

Abstract: Lafrentz, B.R., Kralova, S., Burbick, C.R., Alexander, T.L., Phillips, C.W., Griffin, M.J., Waldbieser, G.C., Garcia, J.C., Dealexandresebastiao, F., Soto, E., Loch, T.P., Liles, M.R., Snekvik, K.R. 2022. Columnaris disease is caused by Flavobacterium columnare and three newly described Flavobacterium spp. [abstract]. International Symposium on Aquatic Animal Health. 208. 9th International Symposium on Aquatic Animal Health, Santiago, Chile. September 5-8, 2022.

Abstract: Lange, M.D. 2021. Use of a Flavobacterium columnare DnaK recombinant protein vaccine to guard against columnaris disease in channel catfish. Proceedings of US-Japan Natural Resources Panel on Aquaculture [abstract]. 13-14.

Database / Dataset: Churchman, E.M., Parello, G., Lange, M.D., Farmer, B.D., Lafrentz, B.R., Beck, B.H., Liles, M.R. 2022. Draft genome sequence of flavobacterium covae strain LV-359-01. National Center for Biotechnology Information (NCBI). SAMN26856627.
Database / Dataset: Churchman, E.M., Parello, G., Lange, M.D., Farmer, B.D., Lafrentz, B.R., Beck, B.H., Liles, M.R. 2022. Draft genome sequence of flavobacterium covae strain LSU-066-04. National Center for Biotechnology Information (NCBI). SAMN26856626.

Database / Dataset: Zhang, D., Lange, M.D., Shoemaker, C.A., Beck, B.H. 2022. Analysis of variation of immunoglobulin (Ig) M transcripts in channel catfish vaccinated with extracellular proteins of virulent Aeromonas hydrophila. National Center for Biotechnology Information (NCBI).

Peer Reviewed Article: Zhang, D., Lange, M.D., Shoemaker, C.A., Beck, B.H. 2022. Identification and characterization of differentially expressed channel catfish IgM transcripts after vaccination with antigens of virulent aeromonas hydrophila. Fishes. 2022(7):24. https://doi.org/10.3390/fishes7010024.

Peer Reviewed Article: Wise, A.L., Lafrentz, B.R., Kelly, A.M., Khoo, L., Xu, T., Liles, M.R., Bruce, T.J. 2021. A review of bacterial co-infections in farmed catfish: Components, diagnostics, and treatment directions. Animals. 11:3240. https://doi.org/10.3390/ani11113240.

Peer Reviewed Article: Lafrentz, B.R., Králová, S., Burbick, C.R., Alexander, T.L., Phillips, C.W., Griffin, M.J., Waldbieser, G.C., Garcia, J.C., De Alexandre, S., Soto, E., Loch, T.P., Liles, M.R., Snekvik, K.R. 2022. The fish pathogen Flavobacterium columnare represents four distinct species: Flavobacterium columnare, Flavobacterium covae sp. nov., Flavobacterium davisii sp. nov. and Flavobacterium oreochromis sp. nov.. Systematic and Applied Microbiology. 45:126293. https://doi.org/10.1016/j.syapm.2021.126293.

Peer Reviewed Article: Prior, B.S., Lange, M.D., Salger, S.A., Reading, B.J., Peatman, E., Beck, B.H. 2022. The effect of piscidin antimicrobial peptides on the formation of Gram-negative bacterial biofilms. Journal of Fish Diseases. 45(1):99-105. https://doi.org/10.1111/jfd.13540.

Peer Reviewed Article: Churchman, E.M., Parello, G., Lange, M.D., Farmer, B.D., Lafrentz, B.R., Beck, B.H., Liles, M.R. 2022. Draft genome sequences of flavobacterium covae strains LSU-066-04 and LV-359-01. Microbiology Resource Announcements. http://doi.org/10.1128/mra.00352-22.

Peer Reviewed Article: Stilwell, J., Griffin, M., Waldbieser, G.C., Stanton, J., Ware, C., Leary, J., Khoo, L., Wise, D., Camus, A. 2022. Myxozoan community composition and diversity in clinical cases of proliferative gill disease in mississippi catfish aquaculture. Journal of Parasitology. 108(2):132 140. https://doi.org/10.1645/21-57.

Peer Reviewed Article: Richardson, B.M., Mischke, C.C., Rosser, G.T., Woodyard, E.T., Ware, C., Wise, D.J., Griffin, M.J. 2022. Non-specific activation of Henneguya ictaluri actinospores. North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10242.

Peer Reviewed Article: Armwood, A.R., Griffin, M.J., Richardson, B.M., Wise, D.J., Ware, C., Camus, A.C. 2022. Pathology and virulence of edwardsiella tarda, edwardsiella piscicida, and edwardsiella anguillarum in channel (ictalurus punctatus), blue (ictalurus furcatus), and channel (female) x blue (male) hybrid catfish. Journal of Fish Diseases. 00:1-16. https://doi.org/10.1111/jfd.13691.

Peer Reviewed Article: Quiniou, S., Crider, J., Felch, K.L., Bengten, E., Boudinot, P. 2022. Interferons and Interferons receptors in the Channel catfish, Ictalurus punctatus. Fish and Shellfish Immunology. https://doi.org/10.1016/j.fsi.2022.02.019.

Peer Reviewed Article: Crider, J.D., Quiniou, S., Felch, K.L., Showmaker, K., Bengten, E., Wilson, M. 2021. A comprehensive annotation of the channel catfish (Ictalurus punctatus) T cell receptor alpha/delta, beta and gamma loci. Frontiers in Immunology. https://doi.org/10.3389/fimmu.2021.786402.

Peer Reviewed Article: Woodyard, E.T., Rosser, T.G., Stillwell, J.M., Camus, A.C., Khoo, L.H., Waldbieser, G.C., Lorenze, W.W., Griffin, M.J. 2022. New data on Henneguya postexilis Minchew, 1977, a parasite of channel catfish Ictalurus punctatus, with notes on resolution of molecular markers for myxozoan phylogeny. Systematic Parasitology. 99(1):41-62. https://doi.org/10.1007/s11230-021-10015-3.

Popular Press Article: Harrison, C., Lafrentz, B.R., Bruce, T.J. 2022. Development of an attenuated columnaris vaccine for catfish and other fish species in the southern region. Fish Farming News. 2022(1):12-13.

Popular Press Article: Lafrentz, B.R. 2021. Catfish columnaris disease cases dominated by one genetic type of Flavobacterium columnare. Fish Farming News. 2021(2):9.

Problem Statement 1C: Improve Catfish Product Quality

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.

Relevant Publication:
Peer Reviewed Article: Bland JM, Ardoin R, Li CH, Bechtel PJ. 2022. Instrumental Texture Differentiation of Channel (Ictalurus punctatus) and Hybrid (Channel × Blue, Ictalurus furcatus) Catfish Fillets. Foods. 11(13):1875. https://doi.org/10.3390/foods11131875

Additional Publications:
Peer Reviewed Article: Bland, J.M., Grimm, C.C., Bechtel, P.J., Deb, U. and Dey, M.M., 2021. Proximate Composition and Nutritional Attributes of Ready-to-Cook Catfish Products. Foods, 10(11), p.2716. https://doi.org/10.3390/foods10112716.

Peer Reviewed Article: Schrader, K. 2022. Impact of diuron applications to commercial catfish ponds on musty-odor cyanobacteria, musty off-flavor compound concentrations, and channel catfish fillet flavor quality . North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10225.

Component 2: IMPROVING THE EFFICIENCY AND SUSTAINABILITY OF SALMONID AQUACULTURE

Problem Statement 2A: Improve Salmonid Aquaculture Production Efficiency and Ensure Product Quality

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.

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.

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.

Relevant Publication:
Peer Reviewed Article: Weber, G.M., Leeds, T.D. 2022. Effects of duration and timing of immersion in 17alpha-methyltestosterone on sex reversal of female rainbow trout. Aquaculture Reports. 23: 101014. https://doi.org/10.1016/j.aqrep.2022.101014.

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.

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.

Additional Publications:

Abstract: Liu, K., Woolman, M.J. 2022. Developing an optimized method for measuring chymotrypsin inhibitor activity in protein products. Meeting Abstract for 2022 AOCS Annual Meeting & Expo, May 1-4, 2022 (hybrid). 2/2. https://22aocs.meetbreakout.com/on-demand/developing-an-optimized-method-for-measuring-chymotrypsin-inhibitor-activity-in-protein-products

Abstract: Liu, K. 2022. Improving and developing sustainable methods for plant protein processing. Meeting Abstract for 2022 AOCS Annual Meeting & Expo, May 1-4, 2022 (hybrid). 1/2. https://22aocs.meetbreakout.com/on-demand/improving-and-developing-sustainable-methods-for-protein-p.

Peer Reviewed Article: Liu, K. 2022. New and improved methods for measuring acid insoluble ash. Animal Feed Science and Technology. 288. Article 115282. https://doi.org/10.1016/j.anifeedsci.2022.115282.

Peer Reviewed Article: Fawole, F.J., Labh, S.N., Hossain, M.S., Overturf, K.E., Small, B.C., Welker, T.L., Hardy, R.W., Kumar, V. 2021. Insect (black soldier fly larvae) oil as a potential substitute for fish or soy oil in the fish meal-based diet of juvenile rainbow trout (Oncorhynchus mykiss). Animal Nutrition. 7(4):1360-1370. https://doi.org/10.1016/j.aninu.2021.07.008.

Peer Reviewed Article: Woolman, M.J., Liu, K. 2022. Simplified analysis and expanded profiles of avenanthramides in oat grains. Foods. 11(4). Article 560. https://doi.org/10.3390/foods11040560.

Peer Reviewed Article: Zarei, M., Amirkolaie, A.K., Trushenski, J.T., Sealey, W.M., Schwarz, M.H., Ovissipour, R. 2022. Sorghum as a potential valuable aquafeed ingredient: Nutritional quality and digestibility. Agriculture. 12(5). Article 669. https://doi.org/10.3390/agriculture12050669.

Peer Reviewed Article: Liu, K. 2022. Method development and optimization for measuring chymotrypsin and chymotrypsin inhibitor activities. Journal of Food Science. 87(5):2018 2033. https://doi.org/10.1111/1750-3841.16141.

Peer Reviewed Article: Sealey, W.M., Conley, Z.B., Hinman, B.T., O'Neill, T.J., Bowzer, J., Block, S. 2022. Evaluation of the ability of Pichia guilliermondii to improve growth performance and disease resistance in rainbow trout (Oncorhynchus mykiss). Journal of the World Aquaculture Society. 53(2):411-423. https://doi.org/10.1111/jwas.12872.

Peer Reviewed Article: Hong, J., Bledsoe, J.W., Overturf, K.E., Lee, S., Iassonova, D., Small, B. 2022. Latitude oil as a sustainable alternative to dietary fish oil in rainbow trout (Oncorhynchus mykiss): Effects on filet fatty acid profiles, intestinal histology, and plasma biochemistry. Frontiers in Sustainable Food Systems. 6. Article 837628. https://doi.org/10.3389/fsufs.2022.837628.

Peer Reviewed Article: Burr, G.S., Peterson, B.C., Gaylord, T.G. 2022. Effects of Histidine on growth performance of North American Atlantic Salmon. Journal of the World Aquaculture Society. 10.1111/jwas.12873.

Peer Reviewed Article: Weber, G.M., Ma, H., Birkett, J.E., Cleveland, B.M. 2022. Effects of feeding level and sexual maturation on expression of genes regulating growth mechanisms in rainbow trout (Oncorhynchus mykiss). Aquaculture. 551: 737917. https://doi.org/10.1016/j.aquaculture.2022.737917.

Peer Reviewed Article: Mankiewicz, J.L., Picklo, M.J., Idso, J.P., Cleveland, B.M. 2022. Evidence of hyperphagia and fatty acid mobilization in leptin receptor deficient rainbow trout (Oncorhynchus mykiss). Biomolecules EISSN 2218-273X. 12(4):516. https://doi.org/10.3390/biom12040516.

Peer Reviewed Article: Bernard, M., Dehaullon, A., Gao, G., Paul, K., Lagarde, H., Charles, M., Prchal, M., Danon, J., Jaffrelo, L., Poncet, C., Patrice, P., Haffray, P., Quillet, E., Dupont-Nivet, M., Palti, Y., Lallias, D., Phocas, F. 2022. Development of a high-density SNP array for rainbow trout genome-wide genotyping. Frontiers in Genetics. 13:941340. https://doi.org/10.3389/fgene.2022.941340.

Peer Reviewed Article: May, T., Good, C., Redman, N., Vinci, B., Xu, F., Østergaard, L., Mann, K. 2022. Efficacy of an enzymatic product (BioRas® Balance) to breakdown hydrogen peroxide following routine treatment applications in aquaculture. Aquaculture Research. https://doi.org/10.1111/are.15927.

Peer Reviewed Article: Crouse, C., Davidson, J., Good, C. 2022. The effects of two water temperature regimes on Atlantic salmon (Salmo salar) growth performance and maturation in freshwater recirculating aquaculture systems. Aquaculture. 553(2022):738063. https://doi.org/10.1016/j.aquaculture.2022.738063.

Peer Reviewed Article: Davidson, J.W., Summerfelt, S., Grimm, C.C., Fischer, G., Good, C. 2021. Effects of swimming speed and dissolved oxygen on geosmin depuration from market-size Atlantic salmon Salmo salar. Aquacultural Engineering. 95:102201. https://doi.org/10.1016/j.aquaeng.2021.102201.

Pre-print Publication: Bernard, M., Dehaullon, A., Gao, G., Palti, Y., Phocas, F., Paul, K., Lagarde, H., Charles, M., Prchal, M., Danon, J., Jaffrelo, L., Poncet, C., Patrice, P., Haffray, P., Quillet, E., Dupont-Nivet, M., Lallia, D. 2022. Development of a high-density 665 K SNP array for rainbow trout genome-wide genotyping. bioRxiv. 488574. https://doi.org/10.1101/2022.04.17.488574.

Review Article: Choudhury, A., Lepine, C., Witarsa, F., Good, C. 2022. Anaerobic digestion challenges and resource recovery opportunities from land-based aquaculture waste and seafood processing byproducts: A review. Bioresource Technology. 354:127144. https://doi.org/10.1016/j.biortech.2022.127144.

Problem Statement 2B: Reduce the Impacts of Disease in Salmonid Aquaculture

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.

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.

Relevant Publication:
Peer Reviewed Article: Liu, S., Martin, K.E., Gao, G., Long, R., Evenhuis, J., Leeds, T.D., Wiens, G.D., Palti, Y. 2022. Identification of haplotypes associated with resistance to bacterial cold water disease in rainbow trout using whole-genome resequencing. Frontiers in Genetics. 13:936806. https://doi.org/10.3389/fgene.2022.936806.

Additional Publications:
Peer Reviewed Article: Bledsoe, J.W., Ma, J., Cain, K., Bruce, T., Rawles, A.A., Abernathy, J.W., Welker, T.L., Overturf, K.E. 2022. Multi-tissue RNAseq reveals genetic and temporal differences in acute viral (IHN) infection among three selected lines of rainbow trout with varying resistance. Fish and Shellfish Immunology. 124:343-361. https://doi.org/10.1016/j.fsi.2022.03.034.

Peer Reviewed Article: Thunes, N.C., Conrad, R.A., Mohammed, H.H., Zhu, Y., Barbier, P., Evenhuis, J., Perez-Pascual, D., Ghigo, J., Lipscomb, R.S., Schneider, J., Li, N., Erbes, D.H., Birkett, C.L., LaFrentz, B.R., Welch, T.J., McBride, M.J. 2021. Type IX secretion system effectors and virulence of the model Flavobacterium columnare strain MS-FC-4. Applied and Environmental Microbiology. 88(3). Article e01705-21. https://doi.org/10.1128/aem.01705-21.

Peer Reviewed Article: Conrad, R.A., Evenhuis, J., Lipscomb, R.S., Birkett, C., McBride, M.J. 2022. Siderophores produced by the fish pathogen Flavobacterium columnare strain MS-FC-4 are not essential for its virulence. Applied and Environmental Microbiology. 88(17). Article e00948-22. https://doi.org/10.1128/aem.00948-22.

Peer Reviewed Article: Ghosh, S., Straus, D.L., Good, C., Phuntumart, V. 2021. Development and comparison of loop-mediated isothermal amplification with quantitative PCR for the specific detection of Saprolegnia spp. PLoS ONE. 16(12):e0250808. https://doi.org/10.1371/journal.pone.0250808.
Peer Reviewed Article: Bledsoe, J.W., Pietrak, M.R., Burr, G.S., Peterson, B.C., Small, B.C. 2022. Symmetry of tissue-specific immune expression and microbiota profiles across mucosal tissues of Atlantic salmon (Salmo salar) highlight host-microbe coadaptations that are marginally perturbed by functional feeds. Animal Microbiome. https://doi.org/10.1186/s42523-022-00173-0.
Peer Reviewed Article: Polinski, M.P., Gross, L., Marty, G.D., Garver, K.A. 2022. Heart inflammation and piscine orthoreovirus genotype-1 in Pacific Canada Atlantic salmon net-pen farms: 2016-2019. BMC Veterinary Research. https://doi.org/10.1186/s12917-022-03409-y.

Peer Reviewed Article: Zhao, J., Vendramin, N., Cuenca, A., Polinski, M.P., Hawley, L., Garver, K. 2021. Pan-Piscine Orthoreovirus (PRV) detection using reverse transcription quantitative PCR. Pathogens. https://doi.org/10.3390/pathogens10121548.

Peer Reviewed Article: Vallejo, R.L., Cheng, H., Fragomeni, B.O., Silva, R.O., Martin, K.E., Evenhuis, J., Wiens, G.D., Leeds, T.D., Palti, Y. 2021. The accuracy of genomic predictions for bacterial cold water disease resistance remains higher than the pedigree-based model one generation after model training in a commercial rainbow trout breeding population. Aquaculture. 545:737164. https://doi.org/10.1016/j.aquaculture.2021.737164.

Trade Journal Article: Good, C., Redman, N., Murray, M., Straus, D.L., Welch, T.J. 2022. Assessing bactericidal activity of peracetic acid to selected fish pathogens in RAS water. Responsible Seafood Advocate. 343.

Component 3: Improving the efficiency and sustainability of hybrid striped bass aquaculture

Problem Statement 3A: Enhance Hybrid Striped Bass Aquaculture Production

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 percent 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.

Publications:
Abstract: Abernathy, J.W., Rawles, S.D., Mcentire, M.E., Sealey, W.M., Gaylord, G.T., Webster, C.D. 2022. White bass broodstock and genome resources development in support of hybrid striped bass aquaculture[abstract]. 2022 North Carolina Aquaculture Development Conference. New Bern, NC. March 10-12, 2022.

Book Chapter: Green, B.W. 2022. Fertilizer use in aquaculture. In Davis, D.A., editor. Feed and Feeding Practices in Aquaculture. Second edition. Cambridge, MA: Woodhead Publishing. p. 29-63. https://doi.org/10.1016/B978-0-12-821598-2.00012-6

Peer Reviewed Article: Mccann, K.M., Rawles, S.D., Lochmann, R.T., Mcentire, M.E., Sealey, W.M., Gaylord, T., Webster, C.D. 2021. Dietary replacement of fishmeal with commercial protein blends designed for aquafeeds in hybrid striped bass (Morone chrysops × Morone saxatilis): Digestibility, growth, body composition, and nutrient retention. Aquaculture Reports. 21. Article 100903. https://doi.org/10.1016/j.aqrep.2021.100903.

Peer Reviewed Article: Green, B.W., Ray, C.L. 2022. Evaluation of settling chamber hydraulic retention time in a Sunshine bass biofloc production system. North American Journal of Aquaculture. 84:165-171. https://doi.org/10.1002/naaq.10229.

Peer Reviewed Article: Rawles, S.D., Fuller, S.A., Green, B.W., Abernathy, J.W., Straus, D.L., Deshotel, M.B., McEntire, M.E., Huskey Jr, G., Rosentrater, K., Beck, B.H., Webster, C.D. 2022. Effects on growth, body composition, and survival of juvenile white bass (Morone chrysops) fed diets without marine fish meal and without supplemental amino acids. Aquaculture Reports. 26. https://doi.org/10.1016/j.aqrep.2022.101307.

Peer Reviewed Article: Schrader, K., Green, B.W., Rawles, S.D., Mcentire, M.E. 2022. Effects of Feed Applications with Various Phosphorus Concentrations on the Abundance of Cyanobacteria and Common Off-flavor Compounds in Hybrid Striped Bass Aquaculture Ponds. Journal of Applied Aquaculture. https://doi.org/10.1080/10454438.2022.2086839.

Component 4: Enhancing Shellfish Aquaculture

Publications:
Peer Reviewed Article: Dumbauld, B.R., Graham, E.R., McCoy, L.M., Lewis, N. 2022. Predicted changes in seagrass cover and distribution in the face of sea level rise: Implications for bivalve aquaculture in a US West Coast estuary. Estuaries and Coasts - Journal of the Estuarine Research Federation. https://doi.org/10.1007/s12237-022-01060-2 .

Peer Reviewed Article: Witkop, E.M., Proestou, D.A., Gomez-Chiarri, M. 2022. The expanded Inhibitor of Apoptosis gene family in oysters possesses novel domain architectures and may play diverse roles in apoptosis following immune challenge. BMC Genomics. https://doi.org/10.1186/s12864-021-08233-6.

Peer Reviewed Article: Witkop, E., Wikfors, G.H., Proestou, D.A., Markey Lundgren, K.R., Sullivan, M.E., Gomez-Chiarri 2022. Perkinsus marinus suppresses in vitro eastern oyster apoptosis via IAP-dependent and caspase-independent pathways involving TNFR, NF-kB, and oxidative pathway crosstalk. Developmental and Comparative Immunology. https://doi.org/10.1016/j.dci.2022.104339.

Component 5: Developing Marine Finfish Seedstocks

Problem Statement 5A: Develop Marine Finfish Seedstocks Optimized for Aquaculture Production Efficiency

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.

Publications:
Peer Reviewed Article: Zhang, D., Mohammed, H., Ye, Z., Rhodes, M., Thongda, W., Zhao, H., Jescovitch, L., Fuller, S.A., Davis, A., Peatman, E. 2022. Transcriptomic profiles of Florida pompano (Trachinotus carolinus) gill following infection by the ectoparasite Amyloodinium ocellatum. Fish and Shellfish Immunology. 125:171-179. https://doi.org/10.1016/j.fsi.2022.05.017.

Peer Reviewed Article: Habte-Tsion, H., Riche, M., Mejri, S., Bradshaw, D., Wills, P.S., Myers, J.J., Perricone, C. 2022. The effects of fish meal substitution by clam meal on the growth and health of Florida pompano (Trachinotus carolinus). Scientific Reports. 12, 7696. https://doi.org/10.1038/s41598-022-11675-x.

Peer Reviewed Article: Yamamoto, F.Y., Ellis, M., Bowles, P.R., Suehs, B.A., Carvalho, P.L., Older, C.E., Hume, M.E., Gatlin Iii, D.M. 2022. The supplementation of a commercial prebiotic, probiotic or their combination affected the production performance and intestinal microbiota of red drum Sciaenops ocellatus L. but did not modulate plasma innate immune response. Aquaculture. https://doi.org/10.3390/ani12192629.

Additional Publications (Not Directly Associated with a Component)

Peer Reviewed Article: Romano, N., Fischer, H., Rubio-Benito, M., Overturf, K.E., Sinha, A., Kumar, V. 2022. Different dietary combinations of high/low starch and fat with or without bile acid supplementation on growth, liver histopathology, gene expression and fatty acid composition of largemouth bass, Micropterus salmoides. Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology. 266. Article 111157. https://doi.org/10.1016/j.cbpa.2022.111157.

Peer Reviewed Article: Lu, X., Deng, D., Huang, F., Casu, F., Kraco, E.K., Newton, R., Zohn, M., Teh, S.J., Watson, A.M., Shepherd, B.S., Ma, Y., Dawood, M.A., Mendoza, L.R. 2022. Chronic exposure to high-density polyethylene microplastic through feeding alters the nutrient metabolism of juvenile yellow perch (Perca flavescens). Animal Nutrition. 9:143-158j. https://doi.org/10.1016/j.aninu.2022.01.007.

Peer Reviewed Article: Shoemaker, C.A., Lozano, C.A., Lafrentz, B.R., Mumma, W.P., Vela-Avitua, S., Ospina-Arango, J., Yazdi, M., Rye, M. 2022. Additive genetic variation in resistance of Nile tilapia (Oreochromis niloticus) to Francisella orientalis and its genetic (co)variation to both harvest weight and resistance to Streptococcus agalactiae Ib. Aquaculture. 561:738736. https://doi.org/10.1016/j.aquaculture.2022.738736.

Peer Reviewed Article: Kaimal, S., Farmer, B.D., Renukdas, N., Abdelrahman, H.A., Kelly, A.M. 2022. Evaluating stress mediated microbial pathogenesis in golden shiners, Notemigonus crysoleucas. Frontiers in Physiology. 13. https://doi.org/10.3389/fphys.2022.886480.

Peer Reviewed Article: Liu, D., Pellicer, A.M., Brüggmann, A., Kiggen, M., Behrens, S., Good, C., Straus, D.L., Meinelt, T. 2021. Effect of water hardness/alkalinity and humic substances on the toxicity of peracetic acid to zebrafish embryos and pathogenic isolates. Aquaculture Reports. 21:10090. https://doi.org/10.1016/j.aqrep.2021.100900.

Peer Reviewed Article: Taghvaei M, Sadeghi R, Smith B. 2022. Seed to seed variation of proteins of the yellow pea (Pisum sativum L.). PLoS ONE 17(8): e0271887.doi.org/10.1371/journal.pone.0271887

Peer Reviewed Article: Chen, D.M., Moore, M., Willis, E.L., Kouba, A.J., Vance, C.K. 2022. The impact of time and environmental factors on the mitochondrial vesicle and subsequent motility of amphibian sperm. Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology. 268:111191. https://doi.org/10.1016/j.cbpa.2022.111191.

Peer Reviewed Article: Santos-Rivera, M., Woolums, A.R., Thoreson, M., Meyer, F., Vance, C.K. 2022. Bovine respiratory syncytial Virus (BRSV) infection detected in exhaled breath condensate of dairy calves by near-infrared aquaphotomics. Molecules. 27(2):549-562. https://doi.org/10.3390/molecules27020549.

Peer Reviewed Article: Heckman, T.I., Shahin, K., Henderson, E.E., Wright, A., Waldbieser, G.C., Griffin, M.J., Soto, E. 2022. Development and efficacy of Streptococcus iniae live-attenuated vaccines in Nile tilapia, Oreochromis niloticus. Fish and Shellfish Immunology. 121:152-162. https://doi.org/10.1016/j.fsi.2021.12.043.

Peer Reviewed Article: Tiwari, A., Woodyard, E.T., Rosser, T.G., Griffin, M.J., Mischke, C.C. 2021. Temperature Modulation and Feed Supplementation Significantly Improve Population Growth of Laboratory-Reared Dero digitata (Annelida: Naididae). North American Journal of Aquaculture. 83:327-335. https://doi.org/10.1002/naaq.10201.

Peer Reviewed Article: Ranjan, R., Sinha, R., Khot, L.R., Whiting, M. 2022. Thermal-RGB imagery and in-field weather sensing derived sweet cherry wetness prediction model. Scientia Horticulturae. 294:110782. https://doi.org/10.1016/j.scienta.2021.110782.

Peer Reviewed Article: Ranjan, R., Sinha, R., Khot, L.R., Hoheisel, G., Grieshop, M.J., Ledebuhr, M. 2021. Effect of emitter modifications on spray performance of a solid set canopy delivery system in a high-density apple orchard. Sustainability. 13(23):13248. https://doi.org/10.3390/su132313248.

Peer Reviewed Article: Hansen, J.D., Ray, K., Chen, P., Yun, S., Elliott, D., Conway, C., Calcutt, M., Purcell, M., Welch, T.J., Soto, E. 2021. Disruption of the Francisella noatunensis orientalis pdpA gene results in virulence attenuation and protection in zebrafish. Infection and Immunity. 89(11):220-21. https://doi.org/10.1128/.