North Central Regional Aquaculture Center

Annual Progress Report 2024-25

December 2025

35th Annual Progress Report

For the Period September 1, 2024 to August 31, 2025

North Central Regional Aquaculture Center

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Executive Summary

This Thirty-Fifth Annual Progress Report provides a summary of work completed and outreach activities of the Administrative Center during the past year. Full progress reports on the multi-year research and Extension projects supported by NCRAC during the reporting period are available at http://www.ncrac.org. NCRAC has funded projects totaling $17,894,775 in more than 20 states and partnered with more than 30 institutions since its inception. Of the total amount funded, $1,012,152 in new projects will be begin in calendar year 2026.

Below are brief summaries of NCRAC funded projects (new projects and multi-year projects) during the current reporting period.

2025 Outputs at a Glance

- Project PI Reports 15 (9 progress; 6 termination)
- Students Supported: 29
- Studies Published or in Advanced Stagesof Development: 7
- Theses & Dissertations: 7
- Digital Products: 21
- Oral Presentations: 81
- Poster Presentations: 7
- Outreach/Extension Presentations: 23

Advancing Aquaculture in the Midwestern Region

Aquaculture is the rearing of aquatic species in controlled and/or selected environments. Ponds and lakes are the most common aquaculture environments in the U.S. Additional production systems include raceways, recirculating systems, non-recirculating tanks and aquaponics. In addition to food-fish production, aquaculture provides sportfish, ornamental fish, baitfish, and aquatic animals for scientific and conservation purposes. Within the last 30 years, aquaculture production of marine and freshwater fish/shellfish has grown from 5% to 50% of global seafood supply and is expected to continue to expand, whereas the wild-caught fish supply cannot expand.

The North Central Regional Aquaculture Center grant targeted expansion of aquaculture production in the midwestern region. If regional aquaculture is to expand, stakeholders must be provided with information as to how to expand into new markets and design cost-effective systems capable of maximizing business performance/economic success.

Application of Bile Acids to Improve Larval Fish Production

This project enhances understanding of how dietary lipid levels and bile acid supplementation influence nutrient absorption, metabolism, and energy use in fish. Through metabolomic analyses, it provides new scientific evidence on the mechanisms by which bile acids improve nutrient utilization and hepatic metabolic balance. Stakeholders gain a clearer understanding of how dietary formulation can be fine-tuned to support better metabolic efficiency without compromising fish growth.

The outcome of this project will encourage feed producers and farmers to adopt optimized diet formulations—specifically, high-lipid diets supplemented with bile acids—to improve feed utilization and reduce nutrient waste. Researchers and extension professionals can integrate these results into training programs and best-practice recommendations, promoting the use of metabolomic tools for feed evaluation and nutrient monitoring.

Asian Carp Muscle as an Initial Dietary Protein Source and Palatability Enhancer for Successful Production of Yellow Perch and Walleye Fingerlings

Limited knowledge of larval/juvenile nutritional requirements, the reliance on live food, poor weaning success to formulated diets, and inefficient utilization of soybean meal-based feeds have

all limited expansion of Percid fingerling production. We propose an innovative dietary protein source and dietary attractant that will precisely match Percid larvae and juvenile requirements and induce high feed intake and positive growth responses when used as first feed and/or during weaning. This innovative dietary protein source will provide more control in production of Percid fingerlings by increasing dry diet acceptance and exposure to plant-based formulation at the earliest possible age. This innovative dietary ingredient and knowledge derived from the study will provide the aquaculture industry particularly in the NCR with the new approach for the development of high-quality starter feeds that will support sustainable expansion of the hatchery sector and consequently contribute to the development of competitive aquaculture market within the NCR.

Development of Consumer Educational Materials on Seafood and Aquaculture

Fish is recognized as a healthy source of protein, beneficial fats, and micronutrients leading the FDA to recommend that adults eat fish up to three times a week. Americans, however, are eating roughly half the recommended amount of seafood. This deficit could be filled by sustainable aquaculture production, reducing our dependence on dwindling wild fisheries. There is, however, substantial consumer confusion surrounding aquaculture and its sustainability, the health benefits of consuming farm-raised fish, and how to prepare and cook fish at home. The overarching goal of this project is to educate the general public about aquaculture and increase the ability of consumers to make informed decisions about aquaculture products through the development of clear, objective, and evidence-based educational materials and engagement activities for both adults and youth (addressing a need repeatedly identified at the 2020 NCRAC listening sessions). We will engage communities through online educational content (e.g., videos), high school and community education curricula, and outreach workshops that educate communities about the health and sustainability of aquaculture. The majority of these materials (as well as detailed templates and protocols for engagement activities) will be made available for future use by educators and extension personnel throughout the NRC.

Evaluation of Laser and Acoustic Non-Lethal Bird Deterrent Technologies for Fish Farms in the North Central Region

Fish loss by bird predation causes substantial economic loss to fish farmers in the North Central Region (NCR). Economic experts estimate that predation losses likely represent at least a $20,000,000 annual loss among all NCR farms. Many farms have implemented deterrents to reduce avian predation but birds can often adapt quickly to new technologies and therefore these systems have had limited success. This project is designed to examine the effectiveness, ease of use, and practicality (e.g. cost/benefit) of acoustic and laser deterrent systems. These systems have been used effectively in other animal agricultural systems (e.g. poultry farms) but their efficacy has not been examined on the avian predators commonly observed in aquaculture. We will also test an integrated pest management (IPM) approach to examine the benefit of combining acoustic deterrents with laser systems and to see if combining techniques can further reduce predation. Acoustic deterrents were recently studied as part of the NCRAC funded rapid response project, “Evaluation of a new bird deterrent system in the North Central Region.” Building on that short-term experiment may help reduce predation. Successfully reducing avian predation loss in aquaculture would benefit producers and lead to a significant decrease in economic loss for NCR farms.

Farmed Fish Fillet as a Functional Food: Technology for Enhanced Fish Diets to Create Value-Added Fish Products

This study concentrates on the analysis of fish performance as it relates to diet including vitamin and flavonoid supplements and optimization of the level that maximizes it (economic efficiency

incentive). Second, studies of fish fillet storage in order to maintain freshness and prevent deterioration of lipid quality, resulting in decrease of consumer acceptance will be related to specific analysis of volatile compounds. Third, one specific process will be addressed that is slowing down of lipid degradation that causes off odors, and results in decreased economic value of fish fillets. Odor is the most common and important quality characteristic used to determine the freshness of fish. Rejection of fish due to off-odors typically occurs at microbial levels between 106-109 CFU/g). The off-odors are typically amines, sulfides, alcohols, aldehydes, ketones, and organic acids.

Fish Preference Analytics Using Social Media and Sentiment Analysis
This project provides insights into perceptions about NCR species allowing producers, industry, researchers and policy makers to gauge public opinion and attitudes. This information then can help industry make appropriate, feasible, and accurate strategic choices.

Impact of Text and Visual Messaging on Consumers: A Consumer Research Study to Inform Aquaculture Messaging, Education, and Producer Training in the NCR
Aquaculture producers in the North Central Region (NCR) have identified aquaculture literacy and consumer education as critical needs to advance industry growth. Lack of education about aquaculture can lead to consumers who are confused and likely discourages consumers from purchasing aquaculture products. In order to inform and attract potential consumers, producers need to understand what marketing messages and attributes of their products motivate consumer purchasing. To understand the most effective marketing strategy, we will engage NCR consumers with various science-based aquaculture promotional messages (text and images). We will collect qualitative and quantitative data from focus groups and a survey to elicit information that interests consumers and leads to an affinity for aquaculture products. We will use the research outcomes to develop a toolkit and teaching curriculum that will be implemented in workshops to teach aquaculture producers about effective messaging and how to apply this information to market their products and improve consumer literacy. Overall, this project will systematically identify consistent, positive, and accurate consumer messaging and empower producers to use these messages to increase consumer demand in the NCR.

Improving Fish Health in the NCR by Integrating Extension with the Development of Alternative Disease Prevention Methods
Per USDA, >28 million US-farmed trout died due to disease in 2019 vs 47 million trout that were sold that same year. Relatedly, producers in the North Central Region (NCR) relayed needs for available fish health expertise to better prevent and control disease. To help NCR producers solve these challenges, our team first leveraged USDA-NIFA NCRAC funds from this project into long-term investment by the College of Veterinary Medicine at Michigan State University to create a regional aquaculture outreach veterinary position that has continued beyond this project into the long-term. This regional aquaculture veterinarian continues to be a highly accessible and beneficial resource for NCR producers. Simultaneously, we paired our industry survey efforts with regionally widespread clinical and flavobacterial recovery methods to create experimental vaccines against bacterial coldwater disease (BCWD), a top disease impediment to trout and salmon production in the USA. Promisingly and despite being exposed to high concentrations of the microbe causing BCWD, not a single vaccinated rainbow trout died from BCWD in a series of multiple month laboratory experiments (in contrast to mock-vaccinated fish that experienced severe disease and mortality). With these tools, we anticipate equipping producers with a means to effectively prevent BCWD in the short/medium term. Per industry feedback, this project has substantially benefited NCR farmed fish health.

Improving Fish Health in the NCR by Integrating Extension with the Development of Alternative Disease Prevention Methods-Part II

Arming producers with practical means of improving farmed fish health in the North Central Region (NCR) was identified as a priority need during the 2020 NCR Aquaculture Roundtable Sessions. The ongoing USDA-NIFA NCRAC funded "Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods" grant yielded a pivotal survey of producers on fish health, which identified many needs and profound support for aquaculture veterinary outreach. Producers from eight NCR states have expressed strong support for Dr. Myron Kebus to continue to provide aquaculture veterinary outreach assistance in the NCR. Since January 2023, he has visited 22 farms, given 36 presentations at aquaculture/veterinary conferences, provided 220 consults to fish farmers and veterinarians, and conducted three major veterinary training workshops. He has linked producers with fish farm veterinarians to reduce costly fish disease losses and obtain fish health certificates for shipping fish, which expands their sales. The grant team leveraged initial NCRAC resources, resulting in the long-term creation of an outreach veterinarian position funded by Michigan State University (MSU). Now armed with that support, what Dr. Kebus needs is only support for travel and supplies to continue greatly benefitting the aquaculture industry throughout the region.

Intensification of First Year Largemouth Bass (Micropterus salmoides) Using Alternative Pond-Based Production Systems

Largemouth bass (*Micropterus nigricans*; LMB) are one of the most popular sportfish in the United States. Whether cultured to a fingerling size for stock enhancement or to the food market size (~ 0.45 – 0.68 kg), cannibalism in low-density production ponds is a major problem for producers, especially during the early growth stage. The PIs proposed investigating intensified alternative production systems for LMB, which would promote (1) reduced cannibalism, (2) lowered feed conversation ratios, (3) improved opportunity for sheltering from piscivorous birds, and (4) increased yields. The alternative systems included a pond-side tank system, and a split-pond system where fish were kept in ~1/3 of the ponds' area. Both systems were designed to increase stocking density and promote improved water circulation and quality. The results of this study highlight the potential improvement in LMB production with split ponds, instead of traditional full ponds. The LMB reared in split ponds showed significantly less variation in size compared to the full ponds, while achieving similar growth, survival, and production efficiency. This more uniform growth can reduce losses associated with cannibalism and reduce labor costs associated with grading fish. Additionally, the split ponds promoted better water circulation and waste removal and provided more ideal water conditions for the LMB, compared to the traditional full ponds. This project provides LMB farmers with novel methods to improve uniform production of LMB fingerlings in the NCR. Scaling split ponds to large-scale commercial production is the next step for determining the utility of this approach.

Physiological and Economic Evaluation of Cold Banking Walleye (*Sander vitreus*) Fingerlings for Year-Round Market Supply

The capacity to bring walleye (*Sander vitreus*) to market at various points during the year remains a challenge for food fish commercialization. One option is to cold bank walleye fingerlings where they are exposed to cold temperatures for a period to slow growth rates before being brought back on to warm water temperatures to resume growth. Although cold banking is a promising approach, there has been little research on adapting the method for walleye producers. It is uncertain how soon after hatching walleye can be cold-banked. This information is important for understanding how much space and feed would be required to cold bank walleye. In addition to the applied research on the practical limitations of cold banking, economic analysis of the viability of the various approaches for staggering cohorts is critical. This project

would evaluate the viability of cold banking walleye both biologically and economically. We will expose fingerling walleye to 1-month cold banking periods at two different ages (60 days post hatch, 120 days post hatch) and evaluate growth rates (before, during, and after cold banking), survival rates, feed requirements, tank volume requirements, and the total cost among treatments. We will use cost information from this study (and previous projects) to evaluate and compare the economic viability of cold banking relative to out-of-season spawning to evaluate which cohort staggering method is most cost effective.

Strengthening Aquaculture Businesses through Collaborative Extension Programming
Creation and delivery of extension and outreach programming, activities, extension products and one-on-one support has the potential to significantly impact NCR aquaculture businesses. It will provide money management skills to both new and seasoned farmers. Knowledge gained in aquaculture business and financial management has the potential to positively impact all types of NCR businesses regardless of systems used to raise aquatic products, species, or intended end use of aquaculture products. The development and delivery of spreadsheets and financial tools will provide projected financial statements for aquaculture businesses in the NCR.

Strengthening Disease Identification, Prevention, and Mitigation in the NCR by providing Fish Farmers with Tools to Respond to Fish Health Problems
Improving farmed fish health in the NCR was identified as a priority need during the 2020 NCR Aquaculture Roundtable Sessions. We are proposing a series of workshops focused on providing theoretical and practical knowledge on fish disease detection, diagnosis, control, and biosecurity, including delivery of hands-on technical skills to fish producers, extension educators and fish health regulators, in Indiana, Illinois, Michigan, Missouri, Minnesota, Ohio, and Wisconsin. In addition, this project includes the evaluation of risk factors associated with morbidity and mortalities on tilapia (*Oreochromis niloticus* hybrids), yellow perch (*Perca flavescens*), and largemouth bass (*Micropterus salmoides*), and will consider other species if time and resources allow it. Later, we will evaluate the interest of fish producers for incorporating vaccination practices to improve fish production and productivity.

Currently, it has been found that only 11% of producers vaccinate, but producers have expressed strong interest in receiving assistance on vaccinating tilapia, largemouth bass, and other important NCR species.

Sustainable Aquaculture: Development of New Quantitative Metrics for Use in Marketing Aquaculture Products
Consumers are increasingly seeking fresh, locally grown, low environmental impact foods. However, data quantifying environmental impact is lacking for aquaculture producers who want to reassure consumers or use in marketing campaigns. This project collected data from 5 aquaculture farms in the North Central Region (NCR) and used life cycle assessment (LCA) to quantify the environmental impacts of existing operations. Species and production systems included largemouth bass and yellow perch in pond culture, rainbow trout in raceways, yellow perch in aquaponic systems, and barramundi in recirculating systems (RAS). Data collected indicated that electricity and feed inputs were the most significant contributors to environmental impact. All aquaculture operations had lower values for global warming potential, acidification and non-carcinogenic impacts when compared to swine production. Fish farms now have quantified data identifying the environmental impact of aquaculture operations and can use those to market their products to consumers.

NCRAC Introduction

Mission
The mission of the Regional Aquaculture Centers (RACs) is to support aquaculture research, development, demonstration, and extension education to enhance viable and profitable U.S. aquaculture, which will benefit consumers, producers, service industries, and the American economy. The North Central Regional Aquaculture Center (NCRAC) serves as a focal point to assess needs, establish priorities, and implement research and extension educational programs in the 12-state agricultural heartland of the United States. NCRAC also provides for coordination of interregional and national programs through USDA's National Coordinating Council for Aquaculture (NCCA). The council is composed of the RAC directors and USDA personnel.

Background
The U.S. Congress has stressed the importance of a strong domestic aquaculture industry to: (1) increase American production of fish and shellfish, (2) reduce dependence on foreign suppliers, and (3) benefit rural America by the development of alternative agricultural crops and creation of new jobs. Recognizing that the aquaculture industry cannot achieve full potential without strong national leadership and direction, the U.S. Congress created an opportunity for making significant progress in aquaculture development in 1980 by passage of the National Aquaculture Act -362). This act addressed the importance of a strong domestic aquaculture industry and established the Joint Subcommittee on Aquaculture (JSA). The JSA is an interagency body that is chaired by the Secretary of Agriculture. It has numerous responsibilities and is to provide coordination and recommendations for Federal aquaculture policy. The Congress also amended the National Agricultural Research, Extension, and Teaching Policy Act of 1977 in Title XIV of the Agriculture and Food Act of 1980 (P.L. 97- 98) by granting authority to USDA to establish aquaculture research, development, and demonstration centers in the United States in association with colleges and universities, State Departments of Agriculture, Federal facilities, and non-profit private research institutions.

Five such centers have been established: one in each of the northeastern, north central, southern, and western regions, and one in Hawaii. As used here, a Center refers to an administrative center currently funded through USDA National Institute of Food and Agriculture (NIFA). Centers do not provide monies for brick-and-mortar development.

Centers encourage cooperative and collaborative aquaculture research and extension educational programs that have regional or national application. Center programs complement and strengthen other existing research and extension educational programs provided by USDA and other public institutions. As a matter of policy, centers implement their programs by using institutional mechanisms and linkages that are in place in the public and private sector.

Organizational Structure
Research and Extension priority areas for the North Central Regional Aquaculture Center (NCRAC) are identified for the north central region by the Industry Advisory Council (IAC), which consists of farmers and industry representatives throughout the region. The Technical Committees (TC), consist of research and extension scientists from states within the region. The two groups then work together to develop "Request for Pre-Proposals" describing the objectives to solve problems identified by the IAC. The pre-proposals reviewed by the IAC are submitted to the NCRAC Board of Directors. The Board selects and approves the pre-proposals for full proposal submission.

The twelve states represented by NCRAC are North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, and Ohio. Funds to operate NCRAC are granted by the USDA-NIFA USDA-National Institute of Food and Agriculture (NIFA) to ISU. ISU disperses funds and serves as legal and fiscal agent in the receipt and disbursement of funds. The Center at ISU also coordinates implementation and operation of individual projects as agreed upon by the Board of Directors as well as fiscal and technical reporting to the USDA-NIFA.

Administrative Center

The Administrative Center is located at Iowa State University, Ames, IA. All support services for the NCRAC Board, IAC, TC-Extension (TC-E), and TC-Research (TC-R) are provided by the Administrative Center. This includes monitoring the status of projects, progress reports, project expenditures, assisting the Iowa State University Office of Sponsored Programs Administration (OSPA) and Sponsored Programs Accounting (SPA) office with project sub-contracts and expenditures, and preparing the annual reports for NIFA.

Funding is approved by the Board for inclusion in the Grant Application submitted annually to USDA NIFA. After approval by NIFA, funds are disbursed to partners via subcontracts to participating institutions. The Center ensures Federal and NIFA guidelines are met.

Members of the administrative team for the current reporting period were:
Stephen J. Dinsmore, Interim NCRAC Director (through December 31, 2024).
Thomas Detmer (January 1, 2025).
Ellen J. Nystrom, Business Manager.

Board of Directors

The Board consists of 11 individuals. There is one representative from the administrative university, Iowa State; North Central Regional Association of State Agriculture Experiment Station (NCRA) Directors; North Central Cooperative Extension Association (NCCEA); 1890 Land-Grant Institutions, and the aquaculture oriented, non-land grant institutions in the region. Those five representative members will serve 4-year terms and may serve more than one term. There will also be four IAC members who will serve as voting members of the Board. The IAC Board members will serve 2-year terms and will be represented by the IAC Executive Committee. Chairs of the two subcommittees of NCRAC's TC will also serve 2-year terms as voting members of the Board. The Board will elect a chairperson from the non-IAC and TC members to serve a 2-year term of office. A chairperson may serve more than one term in office. The Board may approve additional members from 1890 and 1994 Land-Grant institutions, federal and state institutions, and non-profit private institutions in the region.

The Board will:
- Be responsible for overall administration and management of the regional center program.
- Establish overall regional aquaculture research, development, and extension goals, and allocate fiscal resources to ensure that the center develops strong programs both in research and in extension.
- Establish priorities for regional aqua cultural research and extension education activities based on inputs from the IAC and TC and guidance from the National Aquaculture Development Plan.

Members of the Board for the reporting period were:
Paul Brown, Purdue University (Chair); TC-R Representative
James Garvey, Southern Illinois-Carbondale, (Vice-Chair); Non-Land Grant Institution

Representative
Peter Fritsch, Rushing Waters Fisheries, Palmyra, WI; IAC Representative
Josh Gunn, Michigan State University; NCCEA Representative
Emma Hauser, University of Wisconsin-Stevens Point; TC-E Representative
Dan Mosier, State of Kansas; IAC Representative
Phillip Shambach, TIPPCO Fish, Inc., West Lafayette, Indiana; IAC Representative
Jeanette Thurston, NCRA Representative
Barry Thoele, Lincoln Bait, LLC, Staples, MN; IAC Representative
Michael Weber, Iowa State University, ISU Host Instituion Representative (through December 31, 2024)
Stephen Dinsmore, Iowa State University; ISU Host Instituion Representative (starting January 1, 2025)
John Yang, Lincoln University of Missouri; 1890 Land Grant Instituion Representative
Dan Vogler, Harriett Hills Trout Farm, Harrietta MI; IAC Representative (through December 21, 2024)

Industry Advisory Council (IAC)
An IAC is established by the Board. The IAC will consist of 18 individuals. There will be one regular member from each of the 12 state aquaculture associations in the region who will be elected by their membership. Members of the state aquaculture associations will also select an alternate who will participate in business of the Council on occasions when the elected (regular) member cannot do so. The Board will appoint six at-large members to the IAC to assure that various facets of the regional industry are represented on the Council. NCRAC extension contacts in each state will be asked to submit a brief resume for each of not more than two at-large nominees. The Board will select at-large appointees from among those nominated. Members of the IAC (including alternates) will serve 4year terms and all members (including alternates) may serve for more than one term. There will be a rotation of membership. Every two years, one-half of the state aquaculture association representatives and at-large members will be replaced or reappointed. Rotation of the state aquaculture association representatives will be in alphabetical order. A chairperson of the IAC will be elected by the members for a 2-year term of office and may serve more than one term. The IAC provides an open forum wherein maximum input from private and public sectors can be gained and incorporated into annual and ongoing plans for the Center.

The IAC will:
- Recommend to the Board, jointly with the TC, research and extension needs and priorities from an industry perspective;
- Develop with the TC problem statements and objectives for research and extension activities that have been identified for program development;
- Review annual progress reports;
- Recommend to the Board, jointly with the TC, actions regarding new and continuing regional projects and project modifications and terminations.

<u>Members of the IAC for the reporting period were:</u>
Dan Mosier, Kansas Representative (Chair)
Phil Shambach, At-Large Representative (Vice-Chair)
Lyle Andry, Indiana Representative
Ronnie Basler, Illinois Representative
Ben Gollon, At-Large Representative
Jeni Blackburn, At-Large Representative

Ashtyn Chen, At-Large Representative
Margaret Cleveland, Missouri Representative
Marvin Emerson, At-Large Representative
Luke Fredickson, South Dakota Representative
Peter Fritsch, Wisconsin Representative
Curtis Gram, Ohio Representative
Myron Kloubec, Iowa Representative
Bill Murray, Nebraska Representative
Amy Shambach, At-Large Representative
Barry Thoele, Minnesota Representative

Technical Committees
A Technical Committee (TC) is established by the Board. The TC consists of two sub-committees that represent research and is composed of representatives from participating research institutions and representatives from participating State Extension Services, other State public agencies as appropriate, and non-profit private institutions. The TC has two subcommittees: research and extension. Each subcommittee will elect a chairperson to serve a 2-year term of office.

The TC will:
- Recommend to the Board, jointly with the IAC, research and extension needs and priorities from a scientific and extension perspective;
- Develop with the IAC problem statements and objectives for research and extension activities that have been identified for program development;
- Review annual progress reports;
- Recommend to the Board, jointly with the IAC, actions regarding new and continuing regional projects and project modifications and terminations. Technical Committee/Research Membership.

<u>Members of the TC-Research for the reporting period were:</u>
Paul Brown, Purdue University (Chair)
Barbara Evans, Lake Superior State University (Vice-Chair)
David Brune, University of Missouri
Konrad Dabrowski, The Ohio State University
Dong-Fang Deng, University of Wisconsin-Madison
Tyler Firkus, University of Wisconsin-Stevens Point
Dallas Flickinger, Lincoln University of Missouri
Alan Johnson, Iowa DNR
Myron Kebus, Michigan State University
Thomas Loch, Michigan State University
Kevin Neves, Bowling Green University
Allison Pease, University of Missouri
Nicholas Phelps, University of Minnesota
Robert Rode, Purdue University
Kurt Rosentrater, Iowa State University
Dan Sampson, Michigan DNR

Membership of the TC-Extension for the reporting period were:
Emma Hauser, University of Wisconsin-Stevens Point (Chair)
Nicole Wright, The Ohio State University (Vice-Chair)
Joe Gerken, Kansas State University
Paul Hitches, Southern Illinois University-Carbondale
Lauren Jescovitch, Michigan State University-Sea Grant
Elliot Nelson, Michigan State University
Robert Pierce, II, University of Missouri
Kwamena Quagrainie, Purdue University
Herbert Quintero, The Ohio State University
Amy Shrank, University of Minnesota
Kieran Smith, University of Minnesota-Sea Grant

Regular Progress Reports

Project Title: Application of Bile Acids to Improve Larval Fish Production [Progress Report]

Total Funds Committed: $206,045
Initial Project Schedule: January 1. 2024-December 31, 2025 {Extended to December 31, 2026]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Dong-Fang Deng, University of Wisconsin-Milwaukee; Chi Chen, University of Minnesota; Tyler Firkus, University of Wisconsin-Stevens Point
Extension Liaison: Emma Hauser, University of Wisconsin-Stevens Point

Relevance: This project is highly relevant to advancing sustainable aquaculture on the region by improving understanding of nutrient requirements and metabolism of the yellow perch and walleye. The findings provide practical strategies to enhance feed efficiency, reduce waste, and promote healthier, more cost-effective production systems. Ultimately, this work supports the development of nutritionally optimized and environmentally responsible feeds for the aquaculture industry

Response: We investigated potential feed formulations using locally sourced bile acids from pork processing industries, aiming to optimize feed for improving production capacity for yellow perch (*Perca flavescens*) and walleye (*Sander vitreus*).

Results: Four objectives are being pursued in this project:

1. Evaluate the composition of bile acids derived from pork processing by-products and develop feed formulation for feeding trials.
   A two-factor experimental design was used to formulate four practical test diets containing two lipid levels (13% and 17%) and two levels of pork bile supplementation (0% and 0.02%). The bile acid inclusion level was selected based on previous feeding trials. All test diets were analyzed for proximate composition, amino acid and fatty acid profiles, mineral content, and bile acid composition, confirming that measured nutrient levels were consistent with formulation targets. Quantitative analysis of free and conjugated bile acids (bile salts) in 6 feeds showed that glycohyodeoxycholic acid (GHDCA) glycohyocholic acid (GHCA) and glycochenodeoxycholic acid (GCDCA) were major contributed from pig bile were present in the bile acid supplementation diets, but not in other diets. The taurocholic acid (TCA), taurochenodeoxycholate-Na (TCDCA), and chenodeoxycholic acid-Na (CDCA) were the major bile acids presented in the commercial diet.

Sorting Fish for Feeding Trials

2. Evaluating the composition of bile acids derived from pork processing by-products and developing feed formulation for feeding trials.
   A two-factor experimental design was used to formulate four practical test diets containing two lipid levels (13% and 17%) and two levels of pork bile supplementation (0% and 0.02%). The objective was to investigate the interactive effects between dietary lipid level and bile supplementation on fish growth performance, nutrient utilization, and hepatic metabolism. It was hypothesized that bile product supplementation would enhance lipid digestion, nutrient utilization and thus fish overall growth performance. The bile acid inclusion level was selected based on previous feeding trials. A commercial diet was included as a reference (Table 1). All test diets were analyzed for proximate composition, amino acid and fatty acid profiles, mineral content, and bile acid composition, confirming that measured nutrient levels were consistent with formulation targets.

   Two feeding trials were conducted with yellow perch (Perca flavescens) and walleye (Sander vitreus) under flow-through systems with temperature maintained at 20–21 °C. Results for walleye are pending; this report focuses on the yellow perch trial. The trial lasted 12 weeks, with 15 fish per tank and three replicate tanks per diet. Fish (initial body weight 17.9 ± 0.09 g) were fed four meals daily at 1.5–2.5% of estimated body weight.

   The results showed that no significant differences were observed among dietary treatments in fish growth, morphological indices (condition factor, carcass index, hepatosomatic index, visceral fat index), or whole-body proximate composition except for lipid content after 12 weeks. Protein retention was similar across treatments, but lipid retention was significantly higher in fish fed the 13% lipid diets compared with those fed 17% lipid. Conversely, the protein efficiency ratio was higher in fish fed 17% lipid diets. The lowest feed conversion ratio (FCR) and whole-body lipid content were observed in fish fed the 17% lipid diet with bile supplementation, whereas the highest FCR and lipid content occurred in fish fed the 13% lipid diet without bile supplementation. These results suggested that bile acid supplementation may help to improve lipid utilization in perch. The mechanism will be discussed in objective 3

Test Feed Processing

3. Mechanisms through Which Bile Acids Enhance Nutrient Absorption and Metabolism in Larval Fish.
   Feed, liver, and bile samples were analyzed for free amino acids (FAAs), free fatty acids (FFAs), and bile acids using liquid chromatography–mass spectrometry (LC–MS). Liver metabolites were extracted following the Bligh and Dyer method. FFAs were derivatized with 2-hydrazinoquinoline, and FAAs with dansyl chloride before LC–MS analysis on an Acquity™ UPLC–Xevo G2-S QTOF-MS system. Data processing and statistical analyses were conducted using MarkerLynx™, SIMCA-P+, and QuanLynx™ software.

   Liver metabolite profiling revealed clear effects of both dietary lipid level and bile acid supplementation. Fish fed the 17% lipid diet showed higher concentrations of most individual and total FAAs compared with those fed the 13% lipid diet. Likewise, bile acid supplementation increased hepatic FAA levels. In contrast, total FFAs were lower in fish fed 17% lipid diets and tended to decrease further with bile supplementation, although the latter effect was not statistically significant due to variability.

   Two way analysis confirmed that dietary lipid level and bile acid supplementation significantly altered hepatic metabolic profiles. In yellow perch liver, higher dietary lipid levels and bile addition elevated total FAAs but reduced FFAs, suggesting more efficient lipid utilization and conservation of amino acids. These metabolic adjustments indicate that bile acids enhance nutrient absorption and energy metabolism in fish fed high-lipid diets. Although growth performance did not differ among treatments, hepatic metabolism responded strongly to diet composition. Fish fed the low-lipid diet retained more hepatic lipid, likely as a compensatory mechanism to preserve essential fatty acids rather than oxidize them for energy. The higher carbohydrate content of these diets may have also reduced the need for lipid catabolism. Conversely, fish fed high-lipid diets showed improved protein efficiency ratios, implying greater use of lipids for energy and reduced amino acid oxidation, consistent with the higher hepatic FAA levels observed after short-term fasting.

   Bile acid supplementation appeared to further enhance lipid utilization, resulting in higher hepatic FAA concentrations and lower FFAs. The modest increase in FFAs among supplemented groups suggests reduced lipid oxidation, consistent with more efficient energy metabolism.

   In conclusion, these findings suggest that pork bile byproduct supplementation can improve hepatic lipid metabolism in yellow perch. This strategy may support the formulation of high-lipid diets (up to ~17%) that enhance feed utilization and metabolic efficiency while reducing waste—an important consideration for sustainable aquaculture. Ongoing analyses of physiological and health indicators will help clarify the long-term benefits and practical implications of this dietary approach.

4. Conducting extension research to validate the laboratory findings at commercial farms.
   Due to the delayed process of lab study, no extension research was conducted yet. But we have discussed with industrial partners for a plan to have extension research in 2026.

Outreach Overview: The results have not yet been shared with the intended users because the feed formulation is still being finalized and be validated at fish farm to obtain more convincing data. based on ongoing laboratory studies. Currently, we are analyzing samples collected from the last two trials. Once these analyses are complete, new studies will be designed to evaluate an

improved feed for the fish, with plans to begin by March-May 2025 when fish are available. Extension trials will be planned following the completion of these studies.

Targeted Audience: This project is designed to reach a broad range of stakeholders in the aquaculture industry who influence or directly manage feed formulation and production practices. The primary audiences include:

- Aquaculture producers and hatchery managers seeking to improve feed efficiency, growth consistency, and fish health.
- Feed manufacturers and nutritionists responsible for developing cost-effective, high-performance diets.
- Researchers and extension specialists focus on fish nutrition, metabolism, and sustainable feed innovation.
- Policy and industry partners are involved in promoting environmentally responsible aquaculture development.

Outcomes/Impacts: The outcomes of this project will be shared with our targeted audiences, including researchers, the feed industry, pork processing companies, and fish farmers. Feed companies can use the findings to develop new feed formulations that benefit fish farming. Pork processing companies will gain additional avenues for utilizing their byproducts, helping to reduce waste management costs. The findings of this study will also enhance our understanding of fingerling fish nutrition, providing valuable insights for future research.

Partnerships
Peter Shep, Mulberry Aquaponics, LLC
Dave Northey, Northey Fish Farm, LLC
Mike Preul, Mole Lake Fisheries

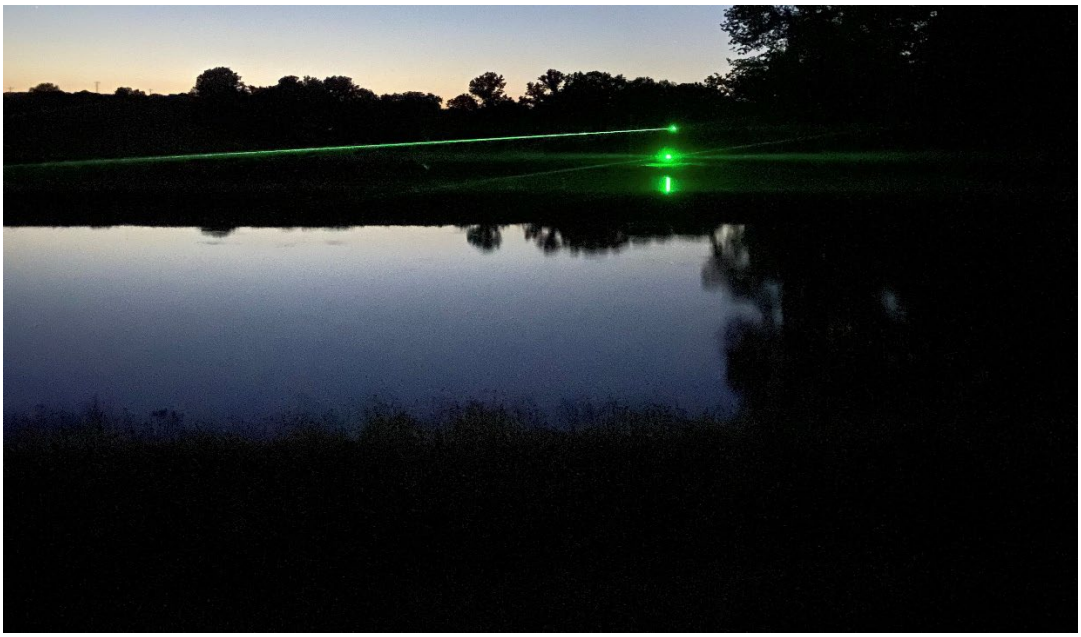
Project Title: Evaluation of Laser and Acoustic Non-Lethal Bird Deterrent Technologies for Fish Farms in the North Central Region [Progress Report]

Total Funds Committed: $101,805 (Year 1), $62,529 (Year 2)
Initial Project Schedule: January 1, 2024-December 31, 2025 [Extended June 30, 2026]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Joe Gerken, Kansas State University; Jason Garvon, Lake Superior State University; Stuart Carlton, Purdue University
Extension Liaison: Amy Shambach, Purdue University

Relevance: Birds are eating fish at aquaculture production facilities which decreases the amount of product these farms can sell. As a result, these farms see risks associated with predation and associated economic impacts.

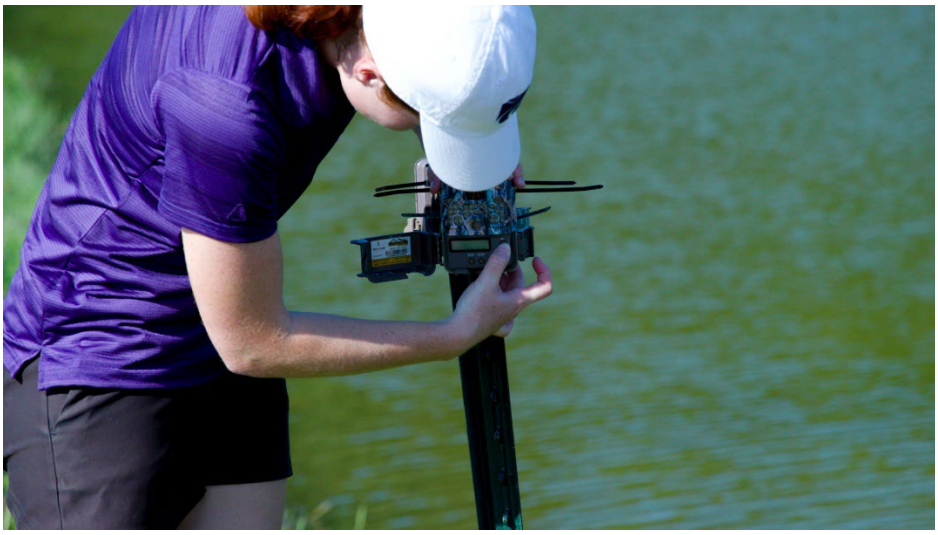
Response: Non-lethal deterrents (laser and acoustics) were installed to decrease avian predation at these sites. Pond dye was also tested as a low cost alternative to the more advanced deterrent technologies'

Results: Four objectives are being pursued for this project:
1-Examine effectiveness of single deterrent (laser system or blanket system) for controlling avian predation at aquaculture production facilities.
Laser and acoustic deterrents were deployed at fish production facilities in three states (Kansas, Michigan, Missouri) over the summer months of 2024. Deterrents were left in place for 28 days to identify habituation of birds over a 4-week timeframe. There was a 7 day recover period after each deterrent to allow birds to reacclimate their behavior in the absence of deterrents.
Over 2.5 million images were collected during a camera trapping survey to help identify the effectiveness of using laser or acoustic deterrents. Additionally, researcher observations were made every ten minutes (day/night) for the two days before and after a deterrent was activated to provide insight into how the deterrents may change the behavior of the birds. A model has been developed to identify presence/absence of avian predators in the camera images. Data analysis is expected to be completed in the spring of 2026.



An Avix Mark ii bird deterrent emits a green laser to discourage birds from feeding at a fish farm in the North Central Region.

2-Examine effectiveness of an integrated pest management approach to avian predation at aquaculture production facilities using a combination of laser and acoustic deterrent systems.
An integrated pest management (IPM) approach was examined to determine if using multiple deterrents was beneficial for deterring birds. This portion of the study was completed at fish farms in Kansas, Michigan, and Missouri and lasted 28 days. Camera traps were deployed and captured over 300,000 images during this period of the study. The AI model mentioned in Objective 1 was used to analyze images and quantify avian predator abundances. Additionally, researchers made observations every ten minutes (day/night) for the two days before and after the IPM approach to examine how birds behavior may change in the presence of deterrents. Data analysis is expected to be completed in the spring of 2026.



K-State graduate student Grace Lansdell program a camera used to monitor bird response to laser and acoustic deterrents.

3-Identify costs associated with acquiring, operating, and maintaining commercially available bird deterrent technologies.
Input costs were tracked during the first two objectives of this study. We have been communicating with producers to gain insight into costs associated with the deterrents while they were at their facilities. We are continuing to collect data so that further analyses can be completed.

4- Develop programming and outreach materials for beginning and experienced farmers describing study results pertaining to outdoor aquaculture facilities and managing problematic birds.
Field days were hosted in three states (Kansas, Michigan, Missouri) by the Principal Investigators of this study. Field days were attended by 22 attendees including industry professionals, students, and researchers. All attendees surveyed rated their overall satisfaction with the field days as satisfied or very satisfied. We also produced an extension video outlining the goals of the project which was shared on YouTube (https://www.youtube.com/watch?v=FSOWhVSqYqc) and various social media accounts associated with the researchers in this study. We are continuing work on producing other outreach materials to share the findings of this study with interested fish farmers.
In addition to the direct objectives mentioned above, we also examined the effectiveness of pond dye as a low-cost bird deterrent technique. Ponds were chosen in Kansas (Milford Fish Hatchery and Farlington Fish Hatchery) and Missouri (Ozark Fisheries) to sample in a paired manner with

an equal number of ponds being dyed and nearby ponds remaining without dye. Pond dye concentrations were monitored and ponds were redyed every 30 days to replinish dye concentrations in the ponds. Ponds were randomly selected to receive dye or remain without dye. Camera trap images were collected at each site for a control period (pre-dye) and then for 60 days while the ponds contained dye, and for 30 days after the final pond treatment period (i.e. 60 total days after the final pond dye application) to examine avian predator abundance at these sites. Over 1 million images were collected among all sites for this portion of the study. These images have been analyzed through the avian predator model mentioned above to identify avian predator abundances and allow for comparisons between dyed and undyed ponds. Data analyses are ongoing and expected to be completed in spring of 2026.

Outreach Overview: We have communicated directly with aquaculture producers and discussed the research and anticipated benefits. This includes direct interactions, multiple inquiries from fish farmers about the status of the project, and in-person field days. An extension video showcasing the problem, research approach, and anticipated results was created using footage at fish farms and interviews with researchers and producers. The video was used to promote outreach events and posted on YouTube (193 views as of 10/29/24) and various social media links where it can be readily accessed by industry professionals.

We organized three field days to introduce producers to the technology being researched in this study. These field days also included university and research experts who could provide further insights into the benefits of the deterrents used in this study.

We have also had conversations about the effectiveness of pond dye as a low cost avian predator deterrent and are developing extension materials that incorporate the effectiveness of pond dye as an avian predator deterrent. We are still early in the process of extending results to producers and look forward to providing additional extension and outreach materials as we move forward.

Target Audience: Our target audience consists of aquaculture producers facing issues with avian predators. Our study is focused on the North Central Region but the results will be beneficial to producers in other regions facing similar problems.

Outcomes/Impacts: Our research will help increase the knowledge of how effective and beneficial laser and acoustic bird deterrents are at aquaculture production facilities. We will also include insights on the effectiveness of pond dye as a deterrent which may be beneficial to smaller producers or producers seeking to cover large areas where other deterrents may not be practical. This knowledge will help producers make better informed decisions on whether to purchase and install these deterrents at their facilities. This knowledge and the action of choosing to invest in deterrents or not will ultimately help producers maximize profits at their facilites and increase the long-term economic viability of fish farms in these regions.

Project Title: Farmed Fish Fillet as a Functional Food: Technology for Enhanced Fish Diets to Create Value-Added Fish Products [Progress Report]

Initial Project Schedule: January 1, 2024-December 31, 2025
Total Funds Committed: $97,326 (Year 1), $111,818 (Year 2)
Current Project Year: September 1, 2024-August 31, 2025
Participants: Sheryl Barringer, The Ohio State University; Christopher Simons, The Ohio State University; Dong-Fang Deng, University of Wisconsin-Milwaukee
Extension Liaison: Herbert Quintero, The Ohio State University
Industry Liaison: Bill Lynch, Millcreek Perch Farm, Ohio

Relevance: The research will verify the extent of inhibition of lipid oxidation caused by the deposition of antioxidants in fish tissue. Lipid oxidation creates both volatiles that produce a "rancid" odor, and a range of carcinogenic oxidation products.

Response: Fish were studied under different rearing and dietary conditions to identify factors influencing off-odor development. For Atlantic salmon, we evaluated the effects of rearing temperature, gender, and the presence or absence of skin on muscle, along with post-harvest storage and cooking methods. These trials provided insight into how environmental and physiological factors drive volatile formation.

For rainbow trout and yellow perch, we focused on diet formulation. Experimental feeds enriched with bioactive plant ingredients including camu camu, maca, wheat, buriti meal, and buriti oil were formulated and tested for their ability to reduce off-odor volatile production. Across all species, we developed and applied advanced volatile analysis methods using selected ion flow tube–mass spectrometry (SIFT-MS) to quantify volatile compounds in real time. Post-harvest protocols were optimized by comparing cooking methods and refrigerated storage time points, enabling the establishment of consistent evaluation standards for assessing diet and processing effects on fish quality.

Results: Five objectives are being pursued in this project:

1. To formulate 5 experimental diets containing (A) enhanced levels of ascorbyl phosphate (1,200 mg AP/kg) and tocopherol acetate (800 mg TA/kg), (B) supplement of flavonoids (myricetin, kaempferol, quercetin, and rutin), (C) a combination of A and B, (D) ethanol/water extract from tropical fruit of aguaje or buriti (Mauritia flexuosa) or Peruvian maca (Lepidium meyeni), and (E) control diet supplemented with the recommended fish diet requirement level of AP and TA.

Student collecting fish samples from tanks using nets for growth and chemical analysis.

2. To perform growth experiments with rainbow trout Oncorhynchus mykiss (OSU) and yellow perch Perca flavescens (UWM) juveniles fed the diets above, but with 26 or 14% lipids, respectively, until there is a 10-fold body weight increase. Growth, diet utilization, and whole-body chemical composition will be examined. A second experiment will use fish of a size so that they will reach marketable size with 60 days of feeding and fillets will be harvested and stored refrigerated for 3, 6, and 12 days.

Rainbow trout length (7 months old). Growth information was collected before processing the fish for laboratory analysis.

3. To analyze muscle lipid content, fatty acid profiles, thiobarbituric acid reactive substances (TBARS) and microbial counts on the fillets.
4. To use Selected Ion Flow Tube Mass Spectrometry (SIFT-MS) to measure the volatiles from fresh, stored, and cooked fillets obtained from 2 species of fish fed the 5 different diets. To measure the effect of ice storage, cooking of fillet from fish fed different diets on both the characteristic and "rancid" volatile compounds generated.
5. To measure the effect of refrigerated storage in association with perception, liking, and food choice using methods of human sensory testing.

This work provided new insights into how diet formulation, rearing conditions, storage environments, lipid distribution, and cooking methods influence the formation of off-odor volatiles in fish. It also established SIFT-MS as a rapid, real-time method for evaluating spoilage-related compounds in aquaculture products. Researchers, aquaculture producers, and feed formulators gained a clearer understanding of the biochemical and environmental drivers of off-odors, expanding the scientific foundation for improving fish quality.

Rainbow trout juvenile (60 days old) reared in 20L tanks equipped with feeding rings.

The project guided practical changes in aquaculture practices and feed strategies. Producers can now incorporate camu camu and maca into rainbow trout diets, and wheat and camu camu into yellow perch diets, to reduce off-odor development. In addition, standardized protocols like using baking as the representative cooking method and three days of refrigerated storage as a sensitive evaluation point for off-odors detection were established to enable consistent assessment of product quality across studies and production settings. These practices provide actionable tools for both research and industry.

By identifying rearing and dietary strategies that reduce off-odor production, the findings contribute directly to improving the shelf life, quality, and consumer acceptance of aquaculture products. These improvements can reduce post-harvest losses, increase profitability for producers, and promote more sustainable and competitive aquaculture systems.

Outreach Overview: We are working with Ohio Sea Grant to incorporate our research findings into one or more of the following materials and/or events: (1) article in Twineline, OHSG's Award-winning quarterly magazine; (2) researcher spotlight in OHSG's monthly e-newsletter, (3) presenter on one of OHSG's "Lake Erie Research Issues Webinar Series"; and/or (4) invited speaker at OHSG's "Decision Makers Day" or "Science Writers Workshop" hosted at Stone Lab.

The investigators will present feeding trials fish performance and fillet storage data at annual Ohio Aquaculture Association meetings, North Central Regional Aquaculture Center conferences, and US Aquaculture Society conferences as well as to Food Industry conferences, such as Institute of Food Technologists Annual Meeting and SIFT-MS User Meeting. Social media through OSU's College of Food, Agriculture, and Environmental Science will additionally be used to communicate results to the community. Periodic posts (quarterly) will be made with updates on current project status, and to remind industry that they may contact the PIs, to increase knowledge transfer.

Targeted Audience: Aquaculture farmers and the fish processing industry.

Outcomes/impacts: This project advanced understanding of how rearing conditions, diet formulation, physiological factors, storage environments, lipid distribution, and cooking methods influence volatile development in aquaculture species. By optimizing SIFT-MS methodology, we established a rapid, real-time tool for detecting spoilage-related volatiles and identified the biochemical origins of rancid and fishy odors in Atlantic salmon, rainbow trout, and yellow perch. These findings expanded fundamental knowledge of the drivers of off-odor formation, linking environmental, nutritional, and processing factors to product quality outcomes.
Our findings guided the design of experimental protocols for assessing off-odors in aquaculture research and practice. In Atlantic salmon, rearing trials demonstrated that cooler temperatures with a light/dark cycle consistently reduced volatile formation compared to warm, continuous-light conditions, providing actionable guidance on environmental management strategies to minimize quality loss before harvest. For rainbow trout, dietary interventions clearly influenced muscle lipid content and volatile profiles. Diets enriched with camu camu and maca were most effective in lowering off-odor compounds, showing that natural, plant-based additives can be incorporated into feed formulations to improve sensory quality without compromising growth. In yellow perch, diets containing wheat and camu camu produced the most stable volatile profiles and reduced the accumulation of rancid aromas. These results highlight that different species respond to dietary modifications, but targeted nutritional interventions can be tailored to reduce spoilage-related odors across aquaculture species.

We also established standardized evaluation methods, baking as the representative cooking process and three days of refrigerated storage as a sensitive time point for consistent detection of volatile differences across species and treatments. Collectively, these results demonstrate that both rearing conditions and diet formulation can be strategically adjusted to control off-odor producing volatile development, and they provide aquaculture producers with practical, evidence-based tools to enhance product quality and consumer acceptance.
Integrating optimized diets with improved rearing, storage, and cooking strategies has the potential to extend the shelf life and marketability of farmed fish. By reducing spoilage-related volatiles, these approaches improve consumer acceptance, reduce economic losses, and contribute to more sustainable aquaculture practices. In the long term, the adoption of these practices will support higher-value aquaculture products and strengthen the competitiveness of U.S. aquaculture in global markets.

No mortality was associated with dietary treatments, and survival rates ranged from 97.5% to 100%. After 9 weeks, fish fed the commercial diet exhibited the highest final body weight and weight gain, significantly exceeding the growth of fish fed the three laboratory-formulated diets ($p < 0.05$). Among experimental diets, yellow perch fed the wheat flour-based diet showed the lowest growth performance, while those fed Camu-camu or mixed starch diets achieved comparable weight gains ($p > 0.05$). Feed conversion ratio did not differ significantly among treatments ($p > 0.05$).

Fish fed the commercial diet had higher condition factor, hepatosomatic index, and Visceral fat compared to those receiving the laboratory diets, although no significant differences were found among the Camu-camu, mixed starch, and wheat flour treatments. Carcass index (yield) was the lowest in fish fed the commercial diet. Protein efficiency ratio (PER) was highest for fish fed the commercial diet but was not significantly different from those fed Camu-camu or mixed starch diets. The lowest PER was observed in fish fed the wheat flour-based diet.

Proximate composition of whole fish did not differ significantly among dietary treatments, indicating consistent nutrient deposition regardless of feed source. However, nutrient retention differed among diets. The commercial diet yielded significantly higher protein and energy retention compared to the wheat flour diet ($p < 0.05$). Fish fed Camu-camu or mixed starch diets had intermediate retention values, not significantly different from either the commercial or wheat flour groups. Lipid retention was highest in fish fed the mixed starch diet, followed by those fed Camu-camu and wheat flour diets, and lowest in those fed the commercial diet.

Overall, replacing wheat flour with Camu-camu improved growth and nutrient retention of juvenile yellow perch without adversely affecting morphological indices, feed conversion, or proximate composition. The performance of fish fed Camu-camu and mixed starch diets was comparable, likely due to higher digestible carbohydrate availability relative to wheat flour. These findings suggest that Camu-camu and mixed starch are promising carbohydrate sources for yellow perch feeds.

The superior performance of fish fed the commercial diet may be attributed to its higher lipid content (15% vs. 13%) and superior physical characteristics (extruded pellets vs. crumbles). Extrusion processing enhances starch gelatinization, improving carbohydrate digestibility and pellet stability in water, which can enhance feed intake and nutrient utilization of commercial diet. However, elevated visceral fat deposition and liver enlargement in fish fed the commercial diet raise potential health concerns that warrant further investigation in longer-term studies.

Project Title: Fish Preference Analytics Using Social Media and Sentiment Analysis [Progress Report]

Initial Project Schedule: January 1, 2024-December 31, 2025 [Extended to October 31, 2026]
Total Funds Committed: $193,452
Current Project Year: September 1, 2024-August 31, 2025
Participants: Kwamena Quagrainie, Purdue University; Amy Shambach, Purdue University; Margaret Lawrence, Purdue University
Extension Liaison: Nicole Wright, The Ohio State University
Industry Liaison: Amy Shambach, TIPPCO Fish, Inc.

Relevance: The U.S. aquaculture industry strives to supply healthy and quality fish products that meet required health and environmental regulations, food safety standards, as well as social and customer acceptability of aquaculture. However, unlike other animal protein production where farming is the norm, fish and seafood in general continues to face public comparisons between wild-caught fish and farmed-fish production. That is why the aquaculture industry continues to address public acceptability challenges through marketing attributes such as sustainability, hormone-free production, animal welfare, eco-labeling, 3rd party certifications, e.g., best aquaculture production practices, etc., to assure quality. Largemouth bass, yellow perch, walleye, bluegill, tilapia and rainbow trout are major aquaculture species in the NCR and every effort should be harnessed to grow production, acceptability and reputation as valuable aquaculture species.

Response: This project applied sentiment analysis to assess online sentiments on select fish species from the Internet of Things (IoT) perspective and quantify positive / negative sentiments associated with the species (farmed and wild-caught) for the U.S. and census regions. We focused on largemouth bass, yellow perch, walleye, bluegill, tilapia and rainbow trout. The analysis has implications for the aquaculture industry in the North Central Region (NCR) because these are major species produced in the region and online chatter would provide valuable insights into consumer mood, perceptions and potential demand signals for these fishes.

Results: Five distinct objectives were pursued in this project. Objectives 1.-4. have been completed. Further data analysis is ongoing. The outreach brochure is being developed for stakeholders and planning workshops for 2025 Fall in Indiana and 2026 Spring in Ohio.

1. Apply sentiment analysis to assess sentiments on major NCR farmed fishes from the Internet of Things (IoT) perspective utilizing online listening tools including social media.
   Online data collection is completed for largemouth bass, yellow perch, walleye, bluegill, tilapia, and rainbow trout. Data is being collected and examined for trends over time.
2. Quantify online sentiments of consumers in terms of positivity and negativity associated with food and sport fishes over time-farmed and wild-caught in the U.S. and various census regions.
   Analysis is ongoing.
3. Categorize online contents and highlight patterns of how people perceive farmed versus wild fish in the food fish and sport fish industries; the change over time, and identifying shocks and relevant events that are associated with the change in sentiments for the U.S. and various census regions.
   Statistical summaries have been completed. The rest of the research is ongoing.
4. Assess implications of online media chatter data for the U.S. aquaculture industry.
   Analysis is ongoing.
2. Develop outreach materials based on results to improve the understanding of Americans'

perceptions of farmed fish online chatter. This will be done in Year 2.

Outreach Overview: Once the outreach brochure is completed, the information will be disseminated to stakeholders by print as well as posting the materials online. The in-person and virtual programs will be done in collaboration with the aquaculture associations in Illinois, Indiana, and Ohio when possible.

Targeted Audience: Producers, industry, researchers and policy makers.

Outcomes/Impacts: Mentions of NCR fish species were generally positive in sentiment. A key finding is that farmed fish consistently received high net sentiment scores just as their wild counterparts, suggesting a favorable public perception of controlled aquaculture practices. Public sentiment toward the fishes is predominantly positive.

Partnerships
Purdue University's Online Sentiment Analysis Group for data collections and analytics.

Project Title: Impact of Text and Visual Messaging on Consumers: A Consumer Research Study to Inform Aquaculture Messaging, Education, and Producer Training in the NCR [Progress Report]

Total Funds Committed: $192,210 (Year 1), $88,534(Year 2)
Initial Project Schedule: January 1, 2025-December 31,2026
Current Project Year: September 1, 2024-August 31, 2025
Participants: Lauren Stigers, Michigan Sea Grant & Michigan State University Extension; Amy Schrank, University of Minnesota Sea Grant; Julia Grenn, University of Minnesota Sea Grant; Stuart Carlton, Purdue University; Donna Moenning, The Center for Food Integrity; Amy Shambach, Illinois-Indiana Sea Grant & Purdue University
Extension Liaison: Amy Shambach, Illinois-Indiana Sea Grant & Purdue University
Industry Liaison: Phil Shambach, TIPPCO Fish, Inc.

Relevance: Aquaculture literacy and consumer education is a critical need to advance industry growth.

Response: Study consumers to determine effective marketing strategies for aquaculture products in the NCR.

Results: Three objectives are being pursued in this project:

1. Identify and evaluate science-based aquaculture messaging to determine the text and visuals that most effectively resonate with consumers.

   We have had some change in personnel: Donna Moenning has replaced Amy and Keely from The Center for Food Integrity as Co-PI, we have added Julia Grenn as a Co-PI, and the PI, although the same, has changed last names from Jescovitch to Stigers. Funds were received in March 2025. As of June 16, we have obtained a Master Service Agreement between Michigan State University and Circana, LLC to conduct the survey and focus group data collection for Obj 1. We have also created a screener and discussion guide for hosting 6 focus groups at the end of October. We have obtained IRB exempt status for human research from Michigan State University. Findings from the focus groups will inform a regional survey that will be developed as the next step for this project.

2. Develop and create a North Central Region (NCR) industry toolkit and training curriculum to increase use of messaging and approaches that build trust and increase iffinity for aquaculture products.

   Team discussions have been on going to inform the focus group and survey data collection to help inform training curriculum. Data will then inform formation of the industry toolkit.

3. Disseminate and deliver training and marketing materials to industry through three regional workshops.

   This objective will be completed in Year 2 of the project.

Outreach Overview
Industry will be invited to receive training in three regional workshops in Year 2 of the project.

Targeted Audience
The North Central Region (NCR) Aquaculture Industry.

Outcomes/Impacts
The overall goal of this project is to train the aquaculture industry to use effective, evidence-based consumer messaging that will lead to increased aquaculture literacy in the NCR.

Short Term
Short term impacts include knowledge gained from conducting this research. These impacts include:
- Increase in access to and knowledge of effective digital marketing elements
- Increase in public knowledge and understanding about aquaculture
- Increase in producers' ability to utilize effective messaging in a marketing strategy

Medium Term
Medium term impacts include behavior changes from conducting this research. These impacts include:
- Consumers relate their food systems and daily life to aquaculture
- Increase consumer acceptance and use of aquaculture products
- Producers adopt knowledge gained and use it in their product messaging.

Long Term
Long term impacts include conditions changed from conducting this research. These impacts include:
- Increase the capacity for producers to provide education on aquaculture
- Create an educated public with a clear, informed understanding of aquaculture
- Develop assessment and community driven models to design future aquaculture education and outreach programs
- Develop and grow consumer demand and aquaculture markets

Partnerships
Circana, LLC, Saratoga Spring, NY
Fusion Marketing Power, Naperville, IL

Project Title: Improving Fish Health in the NCR by Integrating Extension with the Development of Alternative Disease Prevention Methods-Part II [Progress Report]

Total Funds Committed: $14,500 (Year 1), $14,500 (Year 2), $17,500 (Year 3)
Initial Project Schedule: January 1, 2025-December 31,2027
Current Project Year: September 1, 2024-August 31, 2025
Participants: Myron Kebus, Michigan State University

Relevance: Fish farmers presented Dr. Kebus with a range of issues from increased fish mortalities to difficulty in finding an aquaculture veterinarian to conduct regulatory testing for interstate movement of fish. Veterinarians need training to be well equipped to provide aquaculture veterinary services.

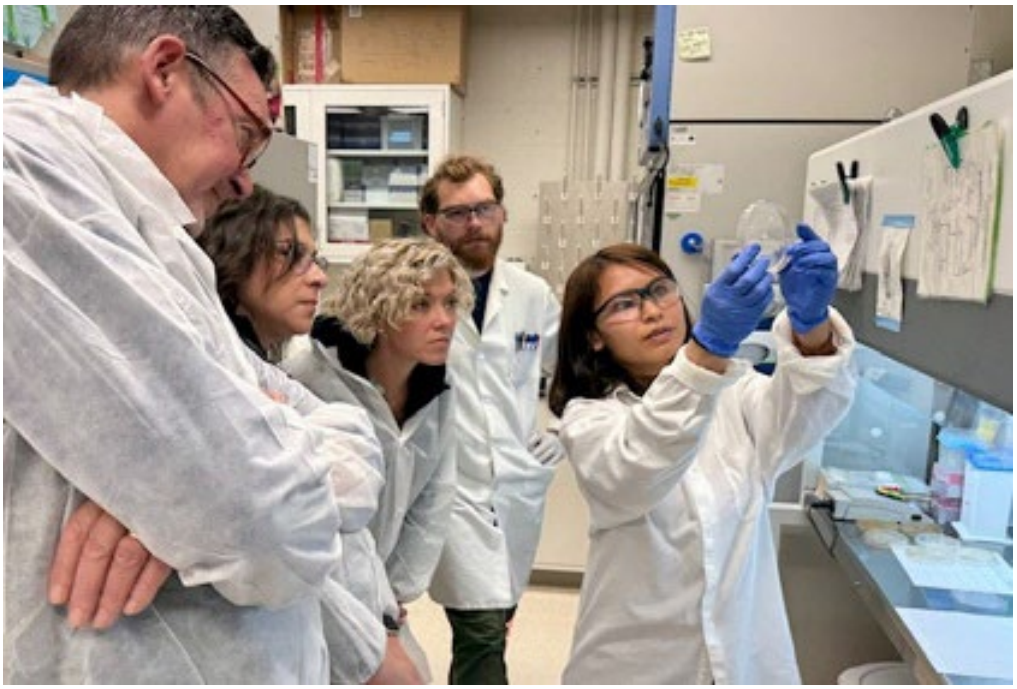
Response: Dr. Kebus helped fish farmers reduce fish mortalities by identifying diseases and providing appropriate treatment and management solutions. He also provided training for veterinarians on aquaculture veterinary medicine.

Results: Five objectives are being pursued in this project:

1. To provide direct assistance to producers through fish health consults on farms.
   Dr. Kebus provided direct assistance to 14 fish farmers from five NCR states (OH, MI, IN, WI, KS). He conducted four in-person farm visits to address fish farmer fish health issues. He was successful in providing direct assistance and helped to reduce fish mortalities.

Fish Vet visit to Ozark, MO

2. To assist veterinarians pursuing fish farm veterinary training by providing consults to veterinarians on farms that request their services.
   Dr. Kebus conducted 12 virtual focus group sessions with over 40 veterinarians to capture collective input on what veterinarians need to know and what resources are needed to provide aquaculture veterinary services to NCR fish farms. He provided direct assistance to 14 veternarians pursuing aquaculture services.



El May Vet Training

3. To conduct producer training workshops on farms to meet specific farm needs for individual farm staff.
   Dr. Kebus provided two customized training workshops on farms (MI, WI) to address the specific needs that the farms requested to be addressed.

Assisting Farmer in Wisconsin

4. To conduct fish farmer and veterinary workshops at conferences and meetings.
   Dr. Kebus conducted a fish farmer workshop at a NCR state aquaculture conference (OH) in January 2025. He presented a half day workshop for veterinarians at the Michigan Veterinary Conference in November 2024.
5. To present findings of issues and concerns of NCR fish farmers at national fish farm and veterinary conferences.
   Dr. Kebus gave oral presentations at four fish farms and veterinary conferences. One was funded by this project; the others were funded by other funding sources. He has been awarded other grants that support some of his activities that benefit NCR fish farmers and veterinarians.

Outreach Overview
Dr. Kebus has delivered oral presentations, poster presentations, website information, and produced scientific publications on his work in the NCR. He has directly communicated by in-person, phone, virtual meetings, emails, and texts the results of his efforts to fish farmers, veterinarians and other NCR stakeholders.

Targeted Audience
The primary target audience is fish farmers in the NCR. These include experienced and new fish farmers. The level of direct assistance depends on the level of experience that the fish farmer has and the specific issues for which they request assistance. The secondary audience is veterinarians who request direct assistance in enhancing their services to NCR fish farmers.

Additional target audiences include veterinary and aquaculture students, fish health regulators, fish diagnostic laboratories and other aquaculture stakeholders.

Outcomes/Impacts
Dr. Kebus has further established his role as the lead contact for fish farmers, veterinarians, and other aquaculture stakeholders in the NCR regarding fish health issues. He has provided direct assistance in determining the causes of fish mortalities on fish farms, provided treatment and fish health management plans, and contributed to the reduction of economic losses associated with fish mortalities.
The impacts include reduced fish mortalities, increased profits, improved fish health, and greater access to well-trained aquaculture veterinarians in the NCR.

Dr, Kebus created with MSU staff a website that has NCR relevant information for fish farmers and veterinarians at https://cvm.msu.edu/research/faculty-research/infectious-disease/aquaculture-outreach.

Successfully conducted with Drs. Thomas Loch and Megan Shavalier the Necropsy and Diagnostic Techniques Workshop, at Michigan State University, East Lansing, MI on May 21 and 22, 2025. This workshop increased the pool of well-trained aquaculture veterinarians in the NCR. The workshop benefitted veterinarians by raising their competence and confidence to provide aquaculture veterinary services to fish farmers.

Project Title: Physiological and Economic Evaluation of Cold Banking Walleye (*Sander vitreus*) Fingerlings for Year-Round Market Supply [Progress Report]

Total Funds Committed: $62,822 (Year 1), $63,648 (Year 2)
Initial Project Schedule: January 1, 2025-December 31, 2026
Current Project Year: September 1, 2024-August 31, 2025
Participants: Tyler Firkus, University of Wisconsin-Stevens Point; Kwamena Quagrainie, Purdue University
Extension Liaison: Emma Hauser, University of Wisconsin-Stevens-Point
Industry Liaison: Colin Bursik, Aqua Garden, LLC

Relevance: The capacity to bring walleye to market at various points during the year remains a challenge for food fish commercialization. Uncertainty around the best option for staggering cohorts leaves new and established walleye aquaculture operations unsure of the best way to proceed.

Response: We are exposing fingerling walleye to 1-month cold banking periods at two different ages (60 days post hatch, 120 days post hatch) and evaluating growth rates (before, during, and after cold banking), survival rates, feed requirements, tank volume requirements, and the total cost among treatments. This information will inform the viability physiologically and economically of cold banking as a strategy for cohort staggering walleye to allow them to be brought to market at multiple times of year.

Results: Five objectives are being pursued in this project:

1. Evaluate ages at which walleye fingerlings can be cold banked.
   Although the project and cold banking trials are still ongoing, preliminary evidence suggests that walleye can successfully be cold banked as early as 60 days post-hatch with few-to-no adverse effects.

2. Quantify and compare growth rates, survival rates, feed conversion, and costs of cold banking walleye fingerlings at different ages.
   The initial 60 DPH cold banking period successfully arrested growth for walleye which resumed following rewarming. The walleye cold banked at 120 DPH similarly displayed arrested growth. As the project continues, relative survival, costs, and feed conversion will be calculated.

3. Use cost information from cold banking trials to compare the economic viability of cold banking relative to multiple cohorts (utilizing out-of-season spawning), and single cohort (not implementing cohort staggering methods) for producing walleye as a fish food.
   The framework of the enterprise budget we will use to compare the economic viability of these approaches has been developed. It will be informed by our trials as they are completed.

4. Provide feed trained fingerlings to industry partners.
   5,381 feed trained walleye fingerlings were provided to industry partners free of charge.

5. Develop outreach deliverables including direct (hands on demonstration, tours, technical assistance) and indirect (presentations, publications, technical videos) targeting industry on the results of this project.
   Details of the methods developed in this study for cold banking walleye have been provided to a start-up company planning to focus on walleye aquaculture. We have additionally assisted with other aspects of facility design and bioplanning. We have also communicated

preliminary results of this project to private walleye aquaculture companies. Once economic modelling is complete, these resources will also be distributed.

Outreach Overview

So far, our results have been extended to the existing private walleye aquaculture industry during regular communications. We have updated four company's technical officers periodically on the result of this project, and have provided feed-trained walleye fingerlings to private industry as part of that communication. Additionally, we have developed other tools for walleye farmers as a result of this project including a modular, age-based feed chart and growth model that takes a lot of the guesswork out of feeding walleye through all stages of growth. The largest aspect of our outreach plan will be enacted after we complete the economic modelling. The fish farmers we are working with are hoping to gain insight into the economic feasibility of different cohort staggering approaches, and the economic modelling and results of our physiological research will provide that information. Once developed, a modular enterprise budget will be available to all interested fish farmers to use and inform their decision making.

Targeted Audience

The primary target audience is fish farmers and operators. We have developed and passed on standard operating procedures for how to cold bank walleye and have created additional tools to assist with feed estimation. An additional target audience is Aquaculture operation owners and capital providers. This research helps operation owners develop plans for bringing their product to market and assists them with the practical aspects of designing aquaculture facilities and bio plans. This research helps private capital have a better understanding of the viability of walleye aquaculture operations and lets them know that there is evidence-based research supporting potential rearing plans.

Outcomes/Impacts

Because this project is still ongoing, the results required to develop outputs are not yet available. Despite this, standard operating procedures, feed charts, and bio planning tools have been shared with fish farmers.

The preliminary results from this project are currently informing system design for two private walleye aquaculture operations. One operation is using a cold-banking approach in the initial planning of their facility and using it to pitch the advantages of cohort staggering to investors. The feed chart we developed is currently in use at three walleye aquaculture operations and we are getting feedback for how to improve it from each. As the enterprise budget deliverable is completed, it will serve as a valuable tool for investors and owners to plan and develop their operations with evidence-based backing.

Partnerships

Aqua Garden, LLC
Woods and Waters Fish Farm, LLC
Fountain Fresh, LLC
Shanghai Wholesale, LLC

Project Title: Strengthening Aquaculture Businesses through Collaborative Extension Programming [Progress Report]

Total Funds Committed: $37,566 (Year 1); $54,902 (Year 2)
Initial Project Schedule: January 1, 2024-December 31, 2025
Current Project Year: September 1, 2024-August 31, 2025
Participants: Kwamena Quagrainie, Purdue University; Amy Shambach, Purdue University, Matt Parker, University of Maryland Extension
Extension Liaison: Nicole Wright, The Ohio State University/Ohio Sea Grant

Relevance: Business planning is severely affected by lack of fundamentally sound financial planning.

Response: This project developed financial planning templates for aquaculture businesses for sound financial and business planning success.

Results: Three distinct objectives were pursued in this project:

1. Provide financial training to aquaculture producers emphasizing the importance of monitoring indicators of profitability, net worth, and available cash for economic success.
   A needs assessment survey was developed and distributed to: 1) identify business/financial challenges of NCR farmers, 2) learn what topics respondents would like to learn about, and 3) collect general information about respondents use of business plans, farm location, and production species. The purpose of the survey was to collect specific information that could be used by the project team to tailor content of training activities to NCR farmers needs/interests. Survey invitations were email to NCR farmers by state aquaculture association representatives. Two state (OH & MO) request hard copy surveys for 2024 state meeting/conference. 27 responses were received between January 26, 2024 and February, 2024. Results were summarized and reviewed by the project team. The level of detail that was anticipated was not realized. Additional information will be collected via informal virtual listening sessions with NCRAC farmers. Next steps are to schedule virtual listening session in order to have conversations with farmers about what they would like to learn during training and to start planning for trainings.
2. Development of templates for enterprise budgets are finished. This will help in gauging net returns. Progress on development of generic templates for Profit/Loss statement, balance sheet, and cash flow and amortization schedules are also in progress. Virtual and in person training will be given during mid 2025 year.
3. Expand producer-facing marketing programming by building on Illinois-Indiana Sea Grant's pre-existing aquaculture marketing seminar.
   Has not yet been completed.

Outreach Overview: Financial planning is fundamental to business success. Templates developed individually to suit respective aquaculture business would enhance financial planning leading to developed business goals and farming success.

Targeted Audience: North Central Region farmers raising aquatic animals for food, stocking, and recreation.

Outcomes/Impacts:

1. Developed generic templates (excel based) for enterprise budget, balance sheet, income statement and cash flow and amortization schedules.
2. Conducted an Aquaculture Business Short Course on 6/6/2025 in Indianapolis, IN. Eight

farmers received copies of the budget templates as well as a text book on aquaculture business planning.

3. Conducted an Aquaculture Business Short Course on 9/12/2025 in Columbus, OH. Seven participants received copies of the budget templates as well as a text book on aquaculture business planning.

Partnerships

Dr. Ganesh Kumar, Mississippi State University
Indiana Aquaculture Association
Ohio Aquaculture Association

Project Title: Strengthening Disease Identification, Prevention, and Mitigation in the NCR by Providing Fish Farmers with Tools to Respond to Fish Health Problems [Progress Report]

Total Funds Committed: $41,954 (Year 1); $55,302 (Year 2); $63,404 (Year 3)
Initial Project Schedule: January 1, 2025-December 31, 2027
Current Project Year: September 1, 2024-August 31, 2025
Participants: Herbert Quintero, The Ohio State University; Myron Kebus, Michigan State University; Amy Shambach, Purdue University
Extension Liaison: Emma Hauser, University of Wisconsin-Stevens Point

Relevance: Fish diseases are one of the major limiting factors to the aquaculture industry in the North Central Region.

Response: We are training fish farmers in recognizing fish diseases; early response (managing water quality, feed management, record keeping and sending fish samples to diagnostic laboratories); and preventing and managing disease outbreaks (biosecurity measures).

Results: Five distinct objectives were pursued in this project:

1. Provide practical training to fish producers on fish diseases and diagnostic practices.
   We will be doing the first fish health training of this proposal on October 8, 2025 at the Ohio Department of Agriculture in Reynoldsburg, Ohio. A total of 18 farmers, 7 students and 2 veterinarians are registered for the training.

2. Identify current fish health practices.
   A semi-structured interview and alternative Qualtrics survey was designed for obtaining information related to current fish health practices. The initial protocol had only the semi-structured interview and was approved by the OSU IRB committee, but the addition of the Qualtrics survey started another process of approval from the IRB committee. Approval was received on 10/7/2025.

3. Introduce minimum standards for fish health record-keeping in the North Central Region.
   The fish health record-keeping practices will be reviewed during the training workshops and mimimum standards will be proposed after having a more thorough understanding of the current fish health record-keeping practices in the region. A summer internship student was introduced to several Ohio farms in Ohio and started to review a set of data from one of those facilities.

4. Introduce a model for fish farmers to identify, prevent, and respond to fish health problems.
   We are going to test these three steps in our first workshop as follows:
   Identification: fish health assessment, signs of disease, collecting and sending fish or tissue samples for laboratory analysis fish necropsy, basic microscope work, and capturing images for disease identification.
   Prevention: training fish farmers on optimum water quality management and feed management to minimize risks of outbreak diseases and improve production, and introduce best standard operating procedures.
   Response: train fish farmers on implementing best biosecurity measurements in fish farm.

5. Develop extension materials and information on fish disease identification, prevention, and response practices.
   Information will start being collected during our first fish health training that will be used to

develop best practices for fish farms in the North Central Region.**utreach Overview**
Results of the first training in Ohio will be presented in the 2026 Ohio Aquaculture Conference, 2026 Annual NCRAC meeting in Iowa, as well as in the Aquaculture America Conference in Las Vegas, NV.

Targeted Audience

- Fish farmers in Ohio and other states in the North Central Region are being actively recruited to participate in our workshops which will provide them with information, and skills to be prepared for a fish/shrimp disease outbreaks and improve fish health practices on fish farms. Ohio farmers will be targeted in 2025. Wisconsin, Indiana and Missouri farmers will be targeted for 2026 trainings. The Wisconsin Aquaculture Association has invited us to do a training prior to their 2026 conference. The Indiana Aquaculture Association has also reached out to request a training for their 2026 annual meeting.
- Veterinarians in the North Central region will be encouraged to participate in the workshops to advance their understanding of fish farmers' fish health needs, and improve their ability to provide aquaculture veterinary services.
- Undergraduate and graduate students in Veterinary, ANR, and other programs that work with the aquaculture industry.

Outcomes/Impacts

Short outcomes that we are targeting include increased knowledge of fish farmers' in diseases, diagnosis and biosecurity practices. We envision as medium outcomes the adoption of improved health management practices by fish farmers, and the establishment of a support network for the aquaculture industry that includes veterinarians and government officials.

Termination Reports

Project Title: Advancing Aquaculture in the Midwestern Region [Termination Report]

Total Funds Committed: $177,158
Initial Project Schedule: January 1, 2024-June 30, 2025 [Extended to August 31, 2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: David Brune, University of Missouri; Paul Brown, Purdue University; Dong-Fang Deng, University of Wisconsin-Milwaukee; Ryan Milhollin, University of Missouri; Mallory Rahe, University of Missouri; Adauto Roacha, University of Missouri; Robert Pierce, University of Missouri; Alice Roach, Kansas State University
Extension Liaison: Kwamena Quagrainie, Purdue University; Simone Valle de Souza, Michigan State University
Industry Liaison: Margaret Cleveland, Ozark Fisheries, Stoutland, MO; Leland Meador, Hanilu Farms, Cutler Indiana

Relevance: At present U.S. aquaculture production provides only 7% of U.S. seafood supply. The majority of U.S. seafood is imported. Development of a cost-effective, environmentally friendly U.S. aquaculture industry offers potential to expand U.S. farm income, while reducing U.S. seafood trade deficit of $25 billion /yr. Life-cycle analysis shows that aquaculture production is more energy efficient and less greenhouse gas intensive when compared to traditional animal agriculture and global fisheries. Expanding Midwestern aquaculture requires understanding and expanding into new markets and developing business models and efficient cost-effective culture systems to maximize production and profitability.

Response: Aquaculture farm site-visits and farmer surveys provided insight into major limitations affecting NCR aquaculture expansion.

Results: The North Central Regional Aquaculture Center grant targeted expansion of aquaculture production in the midwestern region. If regional aquaculture is to expand, stakeholders must be provided with information as to how to expand into new markets and design cost-effective systems capable of maximizing business performance/economic success, To achieve this goal, this work targeted five objectives, 1) Preparation of an overview of trends and outlook of aquaculture in the Midwest based on data from the USDA-Census of Aquaculture, 2) Conduct site visits to aquaculture producers in support of a needs assessment, 2) Conduct a survey of seafood consumers to assess preferences for seafood products and willingness to pay, 4) Prepare enterprise budgets/business models of existing aquaculture production and emerging aquaculture technology and, 5) Prepare an outreach plan conveying project findings and educational materials to university extension specialists within the North Central Region.

NORTH CENTRAL REGION AQUACULTURE TRENDS AND OUTLOOK

The Census of Aquaculture counted 315 farms in the NCR that sold aquaculture products in 2023. These states represent 9.1% of the 3,453 aquaculture farms across the U.S. Ohio had the greatest number in the region at 79, followed by Wisconsin with 74 and Minnesota with 32. Most states have seen a long-term decline in aquaculture farm numbers. NCR states demonstrated growth in number of farms between 2018 and 2023 in Indiana, Kansas, Minnesota, Ohio, South Dakota and Wisconsin.

North Central Regional Aquaculture Sales

According to USDA census, NCR aquaculture farms sold $71.1 million of aquaculture products in 2023. This estimate represents the gross value of sales before marketing and production costs are deducted. Table 1 summarizes NCR aquaculture sales in 2023 and changes from the previous census. NCR states represent 3.7% of U.S. aquaculture sales. It is noteworthy that most NCR states

that reported aquaculture sales demonstrated growth between 2018 and 2023. NCR states' sales grew a collective 66% versus the 26% growth achieved by all U.S. states, not adjusted for inflation. Although NCR states accounted for only 2.5% of food-fish sales, they accounted for more than 20% of aquaculture sales in sport and bait-fish categories.

Smoked trout sales at Freshwater Farms in Ohio

Fresh and Smoked Fish Sales at Rushing Waters Fisheries in Wisconsin

Methods used in production

Production systems used on NCR aquaculture farms include ponds, tanks, flow-through raceways, aquaponics, recirculating aquaculture systems (RAS), and cages or pens. Many species may be cultured in multiple systems, although not all species can be cultured in all production systems. This production system flexibility leads to further complex situations when attempting to identify optimal growth conditions, average growth and survival, feed conversion ratio, and costs of production for a particular species and production system. Despite having a shorter growing season, 80% of NCR farms employ ponds in some phase of aquaculture production, whereas 35% use flow-through raceways, 27% use non-recirculated tanks and 26% use recirculating aquaculture systems, according to the USDA Census

NORTH CENTRAL REGION SITE VISIT; SUMMARY

Ten operating aquaculture farms were visited in Missouri, Illinois, Indiana, Ohio, Wisconsin and Michigan. These sites included operations producing and selling ornamental fish, largemouth bass, barramundi, yellow perch, trout, tilapia, marine shrimp and baitfish. The farmers sold both processed and unprocessed products to retail and wholesale markets, and fish and shrimp to individuals for stocking ponds and recirculating aquaculture systems. During the site visits, the growers were asked to describe their successes, challenges, or opportunities. These were their answers:

1. Improvements in software to track pond fish stocks and sales have played an important role in ornamental fish production and sales profitability.
2. The main challenge in largemouth bass production is ensuring farm profitability.
3. Knowledge supporting barramundi fish farming comes more from farm experience than meetings and fish-farm tours.
4. A major challenge yellow perch farmers face is obtaining a high-quality, cost-effective feed supply.
5. A major challenge for marine shrimp production is ensuring a high survival rate and providing a reliable source of shrimp post larvae (PLs) for stocking.
6. Successful fish farmers must be passionate about raising fish because of the long hours and effort required.
7. A major challenge for selling tilapia fillets is import price competition and the need to sell to ethnic fish markets in the U.S.
8. A promising aquaculture candidate to replace yellow perch is native bluegill sunfish.

9. A major challenge for trout farmers is addressing and correcting misinformation about fish farming.
10. The baitfish industry would benefit from leadership to help influence state and federal regulatory policies.

Sorting Yellow Perch at Millcreek Fish Farm in Ohio

Marine Shrimp Grown at RDM Shrimp in Indiana

MARKETING INSIGHTS FOR MIDWESTERN FOOD-FISH PRODUCERS; SURVEY SUMMARY

The 2025 NCRAC Consumer Survey explored consumer purchasing habits and willingness to pay for common fish species, focusing on gathering consumer sentiment toward aquaculture species suitable for production in the NCRAC region. As such, the 2025 NCRAC survey collected consumer sentiment about fish or seafood species relevant to the NCR. The results/conclusions of this survey are summarized here and under "Willingness to Pay" for seafood products.

1) Most often consumers buy frozen or fresh fish which requires preparation. In 2024, 15% of consumers who bought Great Lakes whitefish, bluegill, bass, grass carp, rainbow trout and barramundi choose prepared options (breaded, marinated, etc.)
2) Compete on quality, not cost. Track production expenses and target niche markets that value sustainability and freshness.
3) Highlight and promote eco-friendly, sustainable practices, safety, and freshness of U.S. farmed fish.
4) Offer prepared samples and preparation demonstration to encourage consumers to try new species.
5) Educate sales teams and consumers on preparation methods. Selling through direct-to-consumer sales channels would allow for "training" shoppers about food preparation methods

WILLINGNESS TO PAY; SURVEY SUMMARY

1) Rainbow trout commands a higher price per lb from consumers outside of Midwest ($32.2) as compared to inside Midwest ($25.51, Table 3).
2) Walleye and yellow perch attract a higher premium price from consumers inside the Midwest.
3) Survey respondents living outside the Midwest place higher value on fresh rather than frozen fillets.
4) Non-Midwesterners are willing to pay a $3.96/lb premium for wild-caught fish. They value fish sourced from the North Central Region and are willing to pay an additional $2.43 per pound for fish sourced from NCR.

NCRAC POND CULTURE AND RECIRCULATING AQUACULTURE BUSINESS MODELS; SUMMARY

Enterprise budgets were prepared for aquaculture entrepreneurs seeking business model examples in the North Central region of the U.S. The North Central region (NCR) aquaculture industry is

diverse. Varied topography, climate, and groundwater availability have guided existing operation locations. Mild winters in the more southern states provide aquaculture pioneers with a more favorable production season than other states. Cold-water species find better growth conditions in the northern NCR states. Nationwide, aquaculture is a growing industry with clusters of highly developed and specialized businesses. Examples of successful regional clusters include trout farms along the rivers of Idaho and catfish operations in the southeastern Mississippi River Delta states. Other areas of the U.S. are home to operations serving exclusively local demand or specific niches and market segments. California has several examples of niche fresh fish operations. Fish market segments could include raising fish for pond stocking; rearing fish for conservation departments and municipalities to fill lakes and rivers; and producing tropical, premium or specialty fish for local food and consumer markets. Business models for 10 different species grown in ponds and another four species grown in recirculating aquaculture systems (RAS) were developed in this study. Departing from a common farm size and RAS structure, the 23 business models detailed in this report were designed to take advantage of emerging aquaculture opportunities, build upon NCR's current industry strengths, avoid apparent weaknesses and steer around threats posed by competitive aquaculture businesses. When combining climate and market factors, it is clear there is no one-size-fits-all operation suitable for North Central region aquaculture. The region has a range of climate conditions and/or water resource availability, which also impacts on the viability of each of the species analyzed in this study. Many times, the conditions present for a startup business are not comparable to those in areas outside the North Central region where large-scale aquaculture markets exist. For these reasons, opportunities for startup aquaculture operations in the North Central region are mostly focused on specialty, or value-added products, at a scale that supports a single-family farm.

Detailed Aquaculture Budgets Prepared for North Central Regional Aquaculture Center Project Available At; https://extension.missouri.edu/programs/aquaculture-and-fisheries-extension/north-central-regional-aquaculture-project

Pond-Raised Recreational Stocking and Food-Fish Aquaculture Budgets; Summary

Farmers can develop custom enterprise budgets for pond-based aquaculture operations by using the pond excel workbook available as referenced above. To utilize these tools, insert known costs, prices or values in gray filled cells. For beginning operators, typical estimates are provided. The "Operating Inputs" spreadsheet contains values that are tied to the requirements for successful operation. The "Capital Inputs" spreadsheet outlines assumptions used for the model operation. Only limited customization in capital and operational inputs is allowed to preserve the functionality of the model. The spreadsheets numbered 1–10 contain outputs for different enterprise models and are specified as sales, markets, and cultured species. Select one or more of these sheets based on the species relevant to the selected operation, customize the species-specific inputs on the right side of the sheet, and view the predicted costs and returns for the modeled operation.

RAS-Raised Recreational Stocking and Food-Fish Aquaculture Budgets; Summary

Farmers can develop custom enterprise budgets for aquaculture RAS operation by using the demonstration budgets. To utilize these tools, insert any known costs, prices or values in gray filled cells. For beginning operators, typical estimates are provided. These budgets are indicative of an operation that serves as full-time occupation for an owner and hired labor. The "Operating Inputs" spreadsheet contains values tied to the operating requirements of each budget. The "Capital Inputs" spreadsheet outlines the long-term assets, equipment, and tools used in the operation. Only limited customization is allowed on this sheet to preserve the functionality of the model. The spreadsheets numbered 1–6 contain outputs for different enterprise models and are named by expected sales, markets, and fish species. Select one or more of these spreadsheets based on the species relevant to

the selected operation, customize the species-specific inputs on the right side of the sheet, and view the estimated costs and returns for the modeled operation. The "Utilities" spreadsheets for each species are hidden for the user's convenience, but can be unhidden if the user feels comfortable making more in-depth changes.

Principal Accomplishments
Approximately 85% of seafood consumed in the U.S. is imported. The U.S. aquaculture industry is emerging, providing a domestic source of seafood products. The North Central Region (NCR) of the Midwestern U.S. has a small evolving aquaculture industry (315 farms), as opposed to the leading U.S. fish-food production states of Mississippi, Alabama, Texas, Idaho and California. Surveys conducted during this study suggest opportunities exist for NCR locally produced seafood products. A survey conducted during this project provides important insights into consumer behavior and seafood purchasing preferences. The survey results suggest that aquaculture offers a significant economic opportunity to Midwestern farmers. Small U.S. fish farms average $115,437 in net profit and with an average of 17.9% return on assets (from 2016 to 2020). This study provides business development resources, updated enterprise budgets specific to the North Central region, and educational materials aiding midwestern farmers, existing and prospective aquaculture producers, investors, and state legislators, informing on the potential economic impact of expanding the aquaculture industry in this region. In addition, outreach activities focus on educating consumers about the sustainability of U.S. aquaculture products as opposed to imported seafood products

Outreach Overview
The project team developed promotional tools to build awareness of the project materials including NCRAC webinars, Facebook posts available to NCRAC Extension pages, news releases distributed to Midwestern media, communications and presentations with NCRAC membership and in-service training to MU and Midwestern Extension faculty. Project materials will be hosted on MU extension aquaculture website and linked to the NCRAC website (https://www.ncrac.org/).

Targeted Audience
The major objective of this project was to provide economic, technical and marketing support to current midwestern conventional farmers, as well as, existing and potential aquaculture farmers, investors, and state legislators on the potential economic impact of expanding the aquaculture industry in the North Central Region. In addition, the extension/outreach activities are intended to educate consumers on the sustainability of U.S. aquaculture production as opposed to imported seafood products.

Outcomes/Impacts
This work targeted current midwestern farmers, existing and prospective aquaculture producers, investors, and state legislators informing on the economic impact of expanding the aquaculture industry in the North Central Region. In addition, outreach activities focus on educating consumers about the sustainability of U.S. aquaculture products as opposed to imported seafood products.

The combined projects, “Next Generation Aquaculture in Missouri” (funded by Missouri Agriculture and Small Business Development Authority) and “Advancing Aquaculture in the Midwestern region,” (funded by North Central Regional Aquaculture Center) led to nine related publications educating the public on the importance of expanding the U.S. aquaculture industry.

Recommended Follow-Up Activities
Future studies should be directed at the growth (or shrinkage) of aquaculture farms and income in

the NCR and cost competition and comparative product quality from imported seafood products as opposed to regional products.

Partnerships
Hanilu Farms, Culter, IN
Ozark Fisheries, Stoutland, MO
RDM Aquaculture, LLC, Fowler, IN
Freshwater Farms of Ohio, Urbana, OH

Project Title: Asian Carp Muscle as an Initial Dietary Protein Source and Palatability Enhancer for Successful Production of Yellow Perch and Walleye Fingerlings [Termination Report]

Total Funds Committed: $198,614
Initial Project Schedule: September 1. 2021-August 31, 2023 [Extended to August 31, 2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Karolina Kwasek, University of New Hampshire; Michal Wojno, Southern Illinois University-Carbondale; Tyler Firkus, University of Wisconsin-Stevens Point
Extension Liaison: Amy Shambach, Illinois-Indiana Sea Grant, Purdue University; Emma Hauser, University of Wisconsin-Stevens Point; Stuart Carlton, Illinois-Indiana Sea Grant, Purdue University
Industry Liaison: Clarence Bischoff, CEO, Blue Water Farms

Relevance: Limited knowledge of larval/juvenile nutritional requirements, the reliance on live food, poor weaning success to formulated diets, and inefficient utilization of soybean meal-based feeds have all limited expansion of Percid fingerling production.

Response: This study proposed an innovative dietary protein source and dietary attractant that will precisely match Percid larvae and juvenile requirements and induce high feed intake and positive growth responses when used as first feed and/or during weaning. This innovative dietary protein source will provide more control in production of Percid fingerlings by increasing dry diet acceptance and exposure to plant-based formulation at the earliest possible age. This innovative dietary ingredient and knowledge derived from the study will provide the aquaculture industry particularly in the NCR with the new approach for the development of high-quality starter feeds that will support sustainable expansion of the hatchery sector and consequently contribute to the development of competitive aquaculture market within the NCR.

Results: Two studies and six objectives are being pursued in this project:

Study 1-Yellow Perch

1. To develop the optimal in vitro methodology for Asian carp muscle digestion using digestive enzymes obtained from adult yellow perch *Perca flavescens* and walleye *Sander vitreus* that can be used as a protein source and attractant in dietary formulations for larval and juvenile yellow perch and walleye.
2. To evaluate the effect of Asian carp muscle digestion using protein hydrolysate obtained in Objective 1 as protein source in diets for yellow and walleye when used as first feed.

Study 1a-Yellow Perch

This study combined the work of many dedicated authors, scientists, and farmers for the successful commercial production of yellow perch larvae using indoor RAS rearing methods. While the industry should further strive for improved performance, yellow perch cultured extensively often experience mortalities greater than 50% (Kestemont 2015). The culture methods used here including 45- and 90-degree surface sprayers, OM-4 ball clay, overhead lighting of black tanks, laminar flow, and variable outlet screen mesh sizes significantly contributed to the successful performance of the larval yellow perch raised using indoor RAS. The silver carp hydrolysate diet did not appear to inhibit the performance of larval yellow perch compared to the other reference diet standards. In fact, the silver carp hydrolysate group tended to perform best in terms of survival; and body length/weight was not significantly different from other groups. The combined RAS technique and diet regimens further opens the door to possibilities of rearing yellow perch in a space efficient, sustainable, and commercially productive manner. These results highlight the need for further research into species specific larval diets for yellow perch and other

percids. It seems a worthwhile endeavor to investigate further the effects which protein hydrolysates can impact juvenile stages of yellow perch and the possible effects which hydrolysates may influence second or third generation larvae.
This study demonstrated a practical use for silver carp, an invasive species in the U.S., for commercial yellow perch rearing. In 2023 there were 340 metric tons of silver carp harvested from just one site over 10 days in the Starved Rock pool of the Illinois River (Loos 2023). Similarly, in Missouri there were 47,000 silver carp harvested and brought to the landfill in 2018 (Chen 2018). While regulations on the use of invasive species can differ by state, and harvesting-processing pose a significant challenge, finding new incentives for the harvest of silver carp could be a major contributor to the control of silver carp in the Mississippi river system. Further attention should be brought to the utilization of silver carp muscle as food for farmed fish. While silver carp is one of the most reared fish in the world, and a primary food source for many cultures, its popularity in the U.S is largely negative and has only really been suggested for use in pet foods and fertilizers. Further attention should be given to alternative uses of silver carp, like the optimization of hydrolysates for larval fish. Further understanding of hydrolyzed larval diets could lead to not only more sustainable fishmeal sources, but improvements in sustainable weaning diets often comprised of difficult to digest alternatives.

Study 1b-Yellow Perch

Ultimately, dependence on live feeds remains to be a major bottleneck for commercial producers. In 2025, the developments of formulated diets have ventured further from groundbreaking and more closely to stepwise progress, often being species specific. To date, no commercial diet exists for Yellow Perch, and as with many other species, a high protein salmonid diet is the standard. From a management standpoint, the fluctuating prices of live feeds and associated labor hours have forced producers to compromise between known advantages of larval rearing with live feeds and associated mortality losses associated with using formulated diets at first-feeding. While formulated commercial diets remain more stable relative to live feeds, cost and time appears to be the driving force for larval management practices. However, there is considerable concern for ecosystem degradation associated with the harvesting of fish for fish oil and equally associated challenges with alternative protein replacements like soybean meal in formulated diets. As live feed usage continues to increase around the world, it will be important to diversify the resources from which live feeds and formulated diet ingredients originate. Moreover, it will be equally important to expand the knowledge around live feed propagation techniques on a species/strain-specific level as it relates to the dynamic of each specific fish species. In doing so, hatchery producers may no longer have to make decisions based entirely on operating cost and move toward the techniques that produce abundant-healthy fish cohorts.

Study 2-Walleye

3. To evaluate the effect of Asian carp muscle protein hydrolysate obtained using methodology in Objective 1 as protein source in diets for yellow perch and walleye when used as first feed.
4. To evaluate the effect of Asian carp muscle protein hydrolysate obtained using methodology in Objective 1 as an additive/palatability enhancer in diets for yellow perch and walleye on successful weaning to formulated feeds.
5. To provide the aquaculture community in the North Central Region (NCR) with guidelines on successful larval reading protocols for both yellow perch and walleye in indoor systems.
6. To provide the feed/additive manufacturing industry with the knowledge and the tools required for production of high-quality well-digested dietary protein hydrolysate as a cost-effective source of protein and attractant for young fish feeds.

In addition to showcasing the importance of hydrolyzed protein derived from same-species digestive enzymes, this study also suggested that utilizing fish meal from other sources, such as a non-native carp species, to produce hydrolysate diets may be a more economically and environmentally sustainable option than currently available marine fish hydrolysate ingredients (as tested with the CPSP diet). The improved growth performance of fish weaned onto the carp muscle diets (hydrolyzed and intact) coupled with the lack of a significant difference in survival indicates that there is room for improvement with currently available diet ingredients. Carp muscle tissue (hydrolyzed or intact) may be a suitable alternative to costly marine fish hydrolysate while reducing reliance on marine resources (Bowzer et al., 2014). Furthermore, the use of carp muscle tissue provides a potential mechanism for assisting population management of carp in non-native waters. Despite the potential advantages of carp muscle tissue as a protein source, our findings suggest that further refinement is required before it can be implemented in commercial walleye larval diets.

Outreach and Extension

The primary focus of outreach and extension as described above (See Objectives 5 and 6) was to 1) disseminated practical information regarding successful larval rearing protocols and research findings to stakeholders interested in rearing yellow perch and walleye larvae fingerlings in indoors systems and 2) provided feed manufactures with the knowledge and the tools for the production of high-quality well-digested diets based on research findings. Outreach and extension accomplishments are:

Provided a one-day hybrid workshop to 63 farmers on larval feeds and intensive early life stage fish culture of commercial important NCR fish species—largemouth bass, yellow perch, and walleye. Total number of attendees at the workshop was 71—60 participants, 11 speakers (three speakers were farmers).

Published recorded workshop talks on UWSP-NADF' YouTube channels and created a workshop playlist. Available online: https://www.youtube.com/playlist?list=PLP8KoWtbBLVy-Zpsxkp1cTQp81VLBP59Y

Provided online access to PowerPoint Presentation after the workshop. Available online: https://uwspedu-my.sharepoint.com/personal/ehauser_uwsp_edu/_layouts/15/onedrive.aspx?id=%2Fpersonal%2Fehauser%5Fuwsp%5Fedu%2FDocuments%2FPROJECTS%2FWALLEYE%2FWalleye%202023%2FAsian%20Carp%20Hydrol%2FWorkshop%20SIU%2FIntensive%20Larval%20Culture%20Workshop%202023%2FFinal%20Presentations%2FIntensive%20Larval%20Culture%20Workshop%202023&ga=1

Created a project page on the UWSP-NADF website. Available online: https://www.uwsp.edu/nadf/northern-aquaculture-demonstration-facility/initial-dietary-protein-source-and-palatability-enhancer-for-successful-production-of-fingerlings/

Provided the opportunity for 11 farmers to tour SIU's aquatics research lab and see operational incubation, larval rearing, fingerling rearing, and live culture systems.

Provided 108 workshop registries with links for workshop resources, recommended resources, and Q&A posted in the chat feature. Speakers were asked to register.

Shot additional AV assets for a practical video guide on larval and fingerling yellow perch rearing.

Created scripts for ten modules for the video guide. Topics covered by modules are cleaning and disinfection, setting up a incubation system, egg incubation, larval rearing tanks, stocking larval

rearing tanks, first feeding, rotifer culture, artemia, cleaning and maintaining larval rearing tanks, and dry feed training.

Informational and instructional based media is currently being developed in conjunction with Purdue University. Media is, so far, planned to be distributed to farmers, public meetings, through Sea Grant, and at national/local aquaculture conferences at least through the year 2023.

The fact sheet entitled *Production and Verification of Fish Muscle Hydrolysate: A Novel Method for Producing Sustainable Dietary Protein* was published.

The ground work has been done for the production of up to 10 video modules on larval yellow perch culture. Production work for Module 1: Clean & Disinfection is complete and Modules 2: Preparing for Eggs: Setting Up Your Incubation Systems, Module 3: Egg Incubation, and Module 4: Larval Rearing Tanks are in progress. Modules 5: Stocking Larval Rearing Tanks and Module 6: First Feeding are in the queue to be worked on next.

The innovative diet formulation and knowledge derived from the study will provide the US industry with new approach for obtaining a high quality cost-effective protein source and development of successful high-quality feeds that will support sustainable expansion of the hatchery sector using RAS systems and consequently contribute to the development of competitive and intensive aquaculture market in the Midwest. These innovative feeds produced using SIUC commercial feed processing method (small scale) will allow for immediate implementation of the formulation by the aquafeed industry.

Increased new knowledge pertaining to rearing of largemouth bass, yellow perch and walleye to NCR residents and non-NCR. Evaluation results indicated that a minimum of 23 NCR residents from seven NCR states (Illinois, Indiana, Kansas, Minnesota, Missouri, Ohio and Wisconsin) attended the workshop. Evaluation response rate was 66.6% based on participant registration (n=60). 39 out of 40 respondents answer the question that asked, “what state do live in”. Non-NCR participants were from Poland, New Zealand, Texas, Canada, New York, Maryland, North Carolina, and Maine.

Increased new knowledge pertaining to larval feeds to NCR residents and non-NCR.
Provided new knowledge that fish culturist intended to implement. 22 attendees said that they were likely or highly to use information from the workshop to implement production methods. One commercial producer planned to implement new knowledge in 2024.

Targeted Audience
Further understanding the response of larval YP to significantly more sustainable ingredients such as Asian carp hydrolysate can benefit more than just further research into larval nutrition. The systems being used at SIUC almost objectively represent the sort of RAS system which real farmers can use to any degree. Creating a practical in vitro hydrolysis process and establishing guidelines for rearing larval YP and other percids has been stated as a high priority by multiple agencies across the NCR. As such, making progress into a more viable supply of fingerlings and larval rearing success can provide benefits that reach out to consumers and policymakers in the long run.

Partnerships
Clarence Bischoff, CEO, Blue Water Farms, Welch, MN
Bill Lynch, Millcreek Perch Farms, Maryville, OH

Recommended Follow-Up Activities

Future studies should focus on live food replacement in percid culture, assessment of nutritional requirements of percid larvae, development of optimal formulated feeds for percid larvae, and improvement of current percid larvae rearing practices towards increased survival, growth. Ad reduced skeletal deformity rate.

Project Title: Development of Consumer Education Materials on Seafood and Aquaculture [Termination Report]

Total Funds Committed: $111,743 (Year 1), $113,762 (Year 2)
Initial Project Schedule: September 1. 2021-August 31, 2023 [Extended to August 31,2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Amy Schrank, University of Minnesota Sea Grant; Elliot Nelson, Michigan State University/Michigan Sea Grant; Barbara Evans, Lake Superior State University; Spark-Y Youth Actions Labs, Minneapolis, MN
Extension Liaison: Lauren Stigers, Michigan State University/Michigan Sea Grant
Industry Liaison: Paul Damhoff, Simply Shrimp, Minnesota

Relevance: Americans are eating roughly half the recommended amount of seafood and most of the seafood we do eat (> 60 %) is imported. There is substantial consumer confusion surrounding aquaculture and its sustainability, the health benefits of consuming local, farm-raised fish, and how to prepare and cook fish at home. This lack of consumer education is a barrier to aquaculture industry growth.

Response: We are increasing the ability of consumers to make informed decisions about aquaculture products through the development of clear, objective, and evidence-based educational materials and engagement activities for both adults and youth. We engage learners through online educational content, high school and community education curricula, and outreach workshops that educate communities about the health and sustainability of aquaculture. We will make these materials available for future use by educators and extension personnel throughout the north central region.

Results

Objective 1: Compile and evaluate readily available resources related to (1) adult consumer education and (2) youth engagement in US aquaculture.

The project team compiled a list of readily available resources by 1) literature review and 2) survey from those who educate others on aquaculture. Additionally, we surveyed those who educate consumers about aquaculture to determine what consumers know, should know, or have misconceptions regarding aquaculture. Results indicate that future efforts with educational interventions should be spent on updating materials to focus on consumer audience, farmed and wild attribute misconceptions, and sustainability of aquaculture in specific contexts. Additionally, the most effective learning experiences are thought to be in-person/virtual tours of farms, online websites, social media, infographics, and fact sheets.

Aquaponics Teacher Workshop (photo credit Elliot Nelson)

Objective 2: Develop, facilitate, and disseminate adult consumer education materials and programming on seafood and aquaculture.

We have worked to develop and disseminate a series of videos, recipes, handouts/factsheets, and workshops/community events with multiple partners to educate adult consumers about local aquaculture. Specifically, we worked with a Michigan farm to develop one, 360 Virtual Reality farm tour, and worked with a local marketing firm to share aquaculture information using three videos on seafood, fishing, and pet fish. We developed a blog, video, and seafood article in partnership with the Portage Health Foundation (now named Copper Shores Community Health Foundation), and three additional recipes in partnership with a chef consultant, Teach to Taste. We developed and disseminated three factsheets that illustrated aquaculture and the benefits of eating local seafood with one in partnership with the marketing agency Taste the Local Difference. Additionally, we facilitated six community events that highlighted and celebrated local aquaculture products and seafood in a variety of ways with consumers. These in-person events utilized many of the products listed above and gathered community members together to have a focused discussion and learn about local aquaculture.

Kiernan Smith and SparkY Interns
(photo credit C. Dettmann)

Objective 3: Develop, facilitate, and disseminate youth educational materials and programming on seafood and aquaculture.

We worked to overcome a major barrier to aquaculture, lack of understanding of aquaculture and familiarity with cooking and eating seafood, through development of educational materials aimed at K-12 teachers and youth. We developed a lesson plan aligned to state science standards on filleting and cooking fish along with an associated coloring page on Great Lakes fishes for consumption. In addition, we created three videos aimed at youth and families about fileting and cooking fish. All these resources are available on the Minnesota Sea Grant website (seagrant.umn.edu). In addition to these resources, members of our project team led the aquaculture challenge and included a seafood cooking component in each project year. We delivered six teacher professional development workshops related to aquaculture and eight events around seafood or aquaculture to youth.

Outreach Overview

Examples of Adult Events:

1) The Mi Fresh Fish Sail and Fry provided a program that celebrates local fish and seafood, and brought awareness of local fish to the general public in a fun and exciting way. These events were held on Friday, July 12, 2024. The sail provided 31 participants with an opportunity to dive deep into learning on the water and the fry provided a snapshot of the breadth of fisheries with seafood cooking and tasting opportunities to 200 people. Results were published in an extension article.
2) The Aquaculture Demonstration tank was displayed at the Wisconsin and Minnesota Aquaculture Association Meeting in 2024. The tank showcased Arctic Cehar from the Northern Aquaculture Demonstration Facility and facilitated conversations on aquaculture misconceptions and production best management practices.

Examples of Teacher and Youth Events:

1) Developed and delivered seafood education programs for youth: Youth Seafood Education Program and 4-H Spin Club on seafood.
2) Collaborated with JKL Anishinaabe Tribal Charter School and the Sault Tribe of Chippewa Indians National Resources Department to develop and deliver Boat 2 School Week to promote learning about how fish are farmed, stocked and harvested in the Great Lakes region.
3) Developed and delivered teacher education programs on aquaponics in the classroom at venues including the Wisconsin Aquaculture Association, Michigan Science Teachers Association, and others.

Targeted Audience

Our target audience was people of all ages who consume and may consume seafood. We also specifically targeted K-12 students and teachers through in classroom, camp and 4-H lessons, the Aquaculture eChallenge, and professional development workshops.

Outcomes/Impacts

- We gathered, organized, and reviewed over 100 resources to provide aquaculture education to either adults or youth learners. This set of resources is available to the public and all interested aquaculture educators at Minnesota Sea Grant's Aquaculture 101 site under the "consumer education on seafood and aquaculture tab": https://seagrant.umn.edu/programs/fisheries-and-aquaculture-program/aquaculture-101

These materials are available for posting to the NCRAC website (www.ncrac.org) and will also be postedt to the updated GLAC website (https://greatlakesseagrant.com/aquaculture/).

- Through a survey of 89 aquaculture educators, we reported on what educators perceive consumers 1) already know about aquaculture, 2) have misconceptions about, and 3) what consumers should know moving forward. Future education interventions should explore content such as aquaculture for food and health, how aquaculture impacts the environment, and how aquaculture can be sustainable.
- For adult consumers, we developed and disseminated five videos, four recipes, three factsheets/handouts, and held six community events.
- During the six community events, we reached over 935 individuals who engaged with local aquaculture and seafood and participated in conversation to learn more about aquaculture through filleting and cooking demonstrations, talking with farmers, and/or taking a virtual farm tour.
- For teachers and youth, we developed one lesson plan aligned to state standards, one coloring sheet, and three videos aimed at youth and families (available on the MNSG website: https://seagrant.umn.edu/programs/fisheries-and-aquaculture-program/kids-cook-seafood-spark-y).
- We provided six professional development workshops about aquaculture/aquaponics to approximately 50 teachers. In addition, we provided seafood and aquaculture education to approximately 400 students through eight events and the Aquaculture eChallenge.

Recommended Follow-Up Activities

Incorporating the findings from this project's work, the project team has worked to develop, facilitate, and disseminate adult and youth educational materials and programming on seafood and aquaculture. A systematically designed approach to these interventions should take into consideration current consumer ideas about aquaculture and use formats such as online educational models, cooking workshops and demonstrations, and lesson plans. These new educational interventions can then be measured (pre/post assessments) to determine how effective they are in increasing consumer knowledge and if specific intervention type or content can address or curb the risk of consumers forming misconceptions. As these interventions are applied, future studies can take a deeper dive into understanding what content and educational format are effective in driving consumer perceptions about aquaculture.

This work has led to additional proposals and will form the foundation of other regional projects. For example, this work directly led to the funding of another NCRAC project titled, "The impact of text and visual messaging on consumers: A consumer research study to inform aquaculture messaging, education, and producer training in the NCR." Here, the project team will examine specific aquaculture messaging that can influence consumers purchasing of local seafood products. Additionally, the materials developed in the current project, including survey results, educator materials, and lessons learned, will be a foundation that will help support the third iteration of the Great Lakes Aquaculture Collaborative project which focuses on advancing aquaculture literacy.

Project Title: Improving Fish Health in the NCR by Integrating Extension with the Development of Alternative Disease Prevention Methods [Termination Report]

Total Funds Committed: $291,591 (Year 1), $309,796 (Year 2)
Initial Project Schedule: September 1, 2021-August 31,2022 [Extended to August 31, 2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Thomas Loch, Michigan State University; Nisha Shrestha, Michigan State University; Nicholas Phelps, University of Minnesota; Myron Kebus, Michigan State University; Matthew A. Smith, YSI/Xylem Analytics
Extension Liaison: Myron Kebus, Michigan State University
Industry Liaison: Dan Vogler, Harrietta Hills Trout Farm

Relevance: According to the USDA National Agriculture Statistics Service (2020) >28 million US-farmed trout were lost due to bacterial and/or parasitic diseases in 2019 compared to 47.2 million trout that were sold that same year, illustrating the substantial disease-induced losses facing US trout producers. In the same vein, producers in the North Central Region continue to relay a need for available fish health expertise to more effectively prevent and control disease-associated losses.

Response: To help NCR producers solve these challenges, our team first leveraged USDA-NIFA NCRAC funds from this project into long-term investment by the College of Veterinary Medicine at Michigan State University to create a regional aquaculture outreach veterinary position that has continued beyond this project into the long-term. This regional aquaculture veterinarian continues to be a highly accessible and beneficial resource for NCR producers. Simultaneously, we paired our industry survey efforts with regionally widespread clinical and flavobacterial recovery methods to create experimental vaccines against bacterial coldwater disease (BCWD), a top disease impediment to trout and salmon production in the USA. Promisingly and despite being exposed to high concentrations of the microbe causing BCWD, not a single vaccinated rainbow trout died from BCWD in a series of multiple month laboratory experiments (in contrast to mock-vaccinated fish that experienced severe disease and mortality). With these tools, we anticipate equipping producers with a means to effectively prevent BCWD in the short/medium term. Per industry feedback, this project has substantially benefited NCR farmed fish health.

Technical Summary:

Obj. 1: Develop practical and usable fish health applications for producers and fish health professionals
During this USDA-NIFA NCRAC funded project, we completed a qualitative semi-structured interview on fish health with North Central Region (NCR) aquaculture producers (representing 24 farms in six NCR states; MI, OH, IN, WI, MN, MO). Although 65% of interviewed farmers participate in regulatory fish health inspections and 44% have a relationship with a fish veterinarian, only 26% have written biosecurity plans, 11% vaccinate, 47% have disinfection protocols, and 4% use Veterinary Feed Directives (VFDs) for antibiotics. Health inspections are a legal requirement for interstate movement of some fish species, and appears to be a leading reason NCR farmers seek veterinary expertise. Many fish farmers under-utilize veterinary services, presenting an opportunity for improved veterinary engagement focused on production and health of farmed fish. Our results provide insight into the needs and perspectives of NCR fish farmers, and full details are published (Kebus et al. 2025).

We learned that use of best management practices (BMPs) to support NCR fish health is

inconsistent. To empower producers to implement effective BMPs, we developed a first of its kind online interactive tool for aquaculture producers using the RShiny platform. A producer can interact with the online tool by answering questions about their farm practices (species, system type, activities, planning, training, monitoring, etc.) and receive a report that highlights opportunities for improvement, summarizes areas of importance, and provides additional resources. Beta testing is underway (expected public dissemination in 2026).

With a goal of improving fish health in the NCR, our team visited fish farms and provided consultations for producers (e.g., fish health management, examination of fish, fish health options and resources in the region). Dr. Kebus did 315 virtual and in-person consults with producers and veterinarians. 183 consults (10 NCR states) focused specifically on active fish health issues, and industry relayed these consults improved a range of NCR fish health and production issues.

Our team gave **64** presentations at local, regional, national, and international professional meetings; led 7 one-day workshops, 4 half-day workshops, and 3 five-day workshops, and gave 26 presentations for veterinarians and veterinary students (*note, our goal in the proposal was 2 one-day workshops*). Notably, NCRAC funds were further leveraged into a long-term investment by the College of Veterinary Medicine (Michigan State University) to indefinitely support an aquaculture outreach veterinary position that continues to positively impact fish health in the NCR.

Obj. 2: Determine the predominating flavobacterial variants in the NCR
With the goal of improving bacterial coldwater disease (BCWD) prevention and control, our team isolated and characterized *Flavobacterium psychrophilum* (*Fp*) variants from the NCR. Moribund salmonids (n=267) were analyzed from 12 facilities in 9 NCR states (MN, MI, OH, WI, IN, IL, IA, MO, SD). Examined fish showed varying disease signs consistent with BCWD, and >340 yellow-pigmented bacteria were recovered, with 194 molecularly confirmed as *Fp*.

Genotyping of representative *Fp* isolates (n=109) via multi locus sequence (MLST) revealed 13 variants (i.e., sequence types, STs), 7 of which were novel (Fig 1). Other recovered *Fp* STs have been detected elsewhere in the USA or only previously reported abroad (Fig 1). Most NCR isolates belonged to a common and widespread Clonal Complex (CC), CC-ST10; however, there was notable *Fp* ST diversity in the region between and also within facilities.

A subset of the *Fp* isolates (n=149) were molecularly analyzed to determine serogroup (SG). Notably, all five known *Fp* SGs were detected within the NCR, with marked variation across states and facilities. Isolates recovered from some NCR states belonged to a single SG, but in other states, multiple SGs were detected in a single facility. Some facilities are battling *Fp* variants similar to other regions of the USA, whereas some facilities face BCWD losses caused by unique regional or farm variants.

Obj. 3: Evaluate the effectiveness of experimental vaccines in preventing losses caused by regionally predominating flavobacteria
Four batches of rainbow trout (RBT; *Oncorhynchus mykiss*) eggs (commercial vendor) were hatched and reared under quarantine in PI-Loch's lab. All eggs were disinfected with iodine upon receipt, and maintained in flow-thru egg stacks until hatching. Alevins were transferred to flow-thru tanks and fed by hand or belt feeder (up to ~2% body weight/day). All four groups were assessed for *Fp* infection (no detections).

Fp variants (n=11) were selected based on recovery location (6 NCR states), genotype (8 STs),

and molecular SGs (4) and used for growth kinetics experiments, with the goal of determining when all variants reach a logarithmic growth phase. Although variation occurred, a common time range was identified.

Prior to vaccine development, the disease/mortality-causing potential of ten diverse NCR *Fp* variants was assessed in ~3-6 month RBT. Fish (n=10/tank, 3x/variant) were adipose fin-clipped, exposed to a variant via immersion, and monitored in aerated, flow-through glass aquaria. All terminally moribund and dead fish were analyzed, and at 27 days post exposure, surviving fish were euthanized and likewise analyzed. Recovered yellow-pigmented bacteria were phenotypically characterized, and representative isolates molecularly analyzed to confirm *Fp.* Cumulative Percent Mortality (CPM) and *Fp* infection status were recorded for each variant.

Disease signs, mortality, and *Fp* infection were not detected in fish exposed to a control or to 3 of the *Fp* variants; however, fish exposed to the other 7 variants developed signs of BCWD, with mean CPM ranging from 3.3 ± 1.6% to 63.3 ± 3.7%. *Fp* was recovered from all dead fish, and from a subset of surviving fish (mean infection prevalence 9.5 – 23.8%). Based on these results, 3 virulent *Fp* variants (representing 3 SGs, 2 STs, and 3 NCR states) were selected for *in vivo* vaccine experiments.

Of note, the health-screening of the third group of fish (intended for vaccination studies) revealed clinical nephrocalcinosis (NC); elevated CO_2 in source well water was identified as a contributing factor. After remediation, new fish were hatched and raised for vaccination. While doing so, our team took the opportunity to study the potential interactions between NC, *Fp*, and vaccination through a series of originally unanticipated experiments. NC-afflicted RBT were exposed to two of the above identified NCR *Fp* variants, and CPM/disease/infection status determined as above. *Fp* infection, BCWD signs, and mortality (CPM from 34.8 ± 0.057% to 46.7 ± 0.1%) suggested NC status altered *Fp* virulence in RBT.

Next, a "pilot" vaccine experiment was undertaken with the NC-RBT. Two *Fp* variants were used to create two "killed" vaccines (i.e., bacterins). NC-RBT were immunized (via intracelomic injection) with a vaccine or mock-vaccine (sterile saline). After ~309 degree-days (dd), fish were booster-immunized via a second injection as before. At ~620 dd total, fish were adipose fin clipped and immersed in the corresponding live *Fp* variant. A group of mock vaccinated fish were exposed to each variant. Mortality occurred only in mock-vaccinated fish and *Fp* was not detected in vaccinated fish (in contrast to mean infection prevalence of 20 – 20.6% in mock-vaccinated fish). Marked differences in external lesion development were also obvious between treatments; active ulceration, swelling, and hemorrhage were evident at the fin clip site in mock-vaccinated fish (Fig 2a, c) compared to clip site healing in vaccinated fish (Fig 2b, d).

Further monovalent vaccine experiments began following histopathological screening of the 4th group of RBT to ensure freedom from clinical NC. Killed vaccines were produced from three geno-/serotypically diverse NCR *Fp* variants (Iso 4, 5, & 11). Three groups of fish (n=100 each) were intracelomically (ic) injected with 1 of 3 vaccines; control fish (n=150) were mock-vaccinated with sterile saline. After 300 dd, fish were booster- or mock-vaccinated using the same procedure as at time 0. After ~600 dd total and following adipose fin clip, vaccinated and mock-vaccinated fish were immersed in a respective *Fp* suspension, whereas negative control fish were immersed in tank water containing an equivalent volume of sterile saline. Fish (10 per tank, 3x by treatment), were observed/sampled/analyzed as above, and monitored for 27 days, at which time survivors were euthanized and sampled. CPM, relative percent survival (RPS), and *Fp* infection status were recorded for each treatment.

No mortality occurred in any *Fp*-exposed vaccinated fish, nor in any control fish (Fig 3). In contrast, mean CPM in mock-vaccinated, *Fp* exposed fish was 46.7% (iso-5), 63.3% (iso-4), and 80% (iso-11; Fig 3). Thus, RPS was 100% for fish vaccinated with each preparation. *Fp* was recovered from all mock-vaccinated dead fish, but not from any negative control fish. Promisingly, *Fp* infection was detected in the surviving/euthanized, mock-vaccinated, *Fp* exposed fish at high prevalence (50% - 72.7%), but only in one vaccinated group and at low prevalence (1/30 fish; 3.3%).

To create a trivalent vaccine, the same three *Fp* variants were prepared as above and mixed in equal ratios. Vaccinated fish (220) were ic injected with the vaccine, whereas mock-vaccinated control fish (220) received sterile saline only. After 306 dd, fish received a second injection as before. After ~606 dd total, vaccinated and mock-vaccinated fish were immersed in an *Fp* suspension of each of the three *Fp* variants individually, whereas negative control fish were immersed in tank water containing an equivalent volume of sterile saline. Fish were observed/analyzed as above, monitored for 27 days, and survivors euthanized. CPM, RPS, and *Fp* infection status were recorded.

No mortality occurred in vaccinated *Fp* exposed fish, nor in any negative control fish (Fig 4). In contrast, mean CPM in mock-vaccinated, *Fp* exposed fish was 13.3% (iso-5), 73.3% (iso-4), and 93.3% (iso-11; Fig 4). Thus, RPS was 100% for fish vaccinated with the trivalent vaccine. *Fp* was recovered from all mock-vaccinated dead fish. Notably, while *Fp* infections were detected in the euthanized, mock-vaccinated *Fp* exposed fish (prevalence 65.4% - 100%), *Fp* was not detected in any vaccinated fish.

Results: Three objectives are being pursued in this project:

1. Develop practical and usable fish health applications for producers and fish health professionals through farm visits, trainings, and the creation of pragmatic resources by NCR fish health veterinarians.
   - Published papers on fish health issues in the NCR
     - https://avmajournals.avma.org/view/journals/javma/263/8/javma.25.01.0037.xml
     - https://avmajournals.avma.org/view/journals/javma/263/11/javma.25.06.0371.xml
   - Conducted fish health workshops for fish farmers
   - Conducted fish health workshops for aquaculture veterinarians
   - Conducted customized fish health workshops for fish farms that requested staff training
   - Provided on-farm fish health consults to address critical fish health problems
   - Provided phone consults for critical fish health problems
   - Conducted training of veterinary students on aquaculture veterinary medicine
   - Developed a MSU CVM website on Aquaculture Veterinary Outreach for Fish Farmers and Veterinarians https://cvm.msu.edu/research/faculty-research/infectious-disease/aquaculture-outreach
   - Developed innovative online and interactive tool that allows farmers to evaluate site-specific best management practices for fish health and identify resources to reduce risk.

2. Determine, for the first time, the predominating flavobacteria variants driving economic losses in the NCR.
   - Collected and analyzed more than 250 moribund salmonids from 12 facilities located in 9 (MN, MI, OH, WI, IN, IL, IA, MO, SD) of the 12 states within the NCR.

- Recovered >340 yellow-pigmented bacteria from the sampled fish, including 194 that were molecularly confirmed as *F. psychrophilum*.
- Created a preserved cryobank of the recovered flavobacteria (being maintained in PI-Loch's laboratory)
- Generated novel MLST-derived genotyping data for > 100 *F. psychrophilum* isolates that originated from nine different facilities in seven of the sampled nine NCR states.
- Generated novel molecular serogrouping data for > 140 *F. psychrophilum* isolates that originated from nine different facilities in seven of the sampled nine NCR states.
- Uncovered important epidemiological trends for *F. psychrophilum* within the NCR, including identifying widespread serogroups and genotypes, as well as those that were unique to some states and/or facilities.
- Generated a data-derived road-map for potentially "higher priority" *F. psychrophilum* variants within the NCR.

Dr. Loch with Students

3. Evaluate the effectiveness of experimental vaccines in preventing losses caused by regionally predominating flavobacteria under laboratory and field conditions.
   - Characterized the disease and mortality causing potential of ten NCR *F. psychrophilum* variants in rainbow trout via controlled *in vivo* laboratory experiments.
   - Developed and tested the protective efficacy of three newly developed experimental BCWD vaccine preparations (monovalent bacterins), derived from three distinct *F. psychrophilum* variants (representing different genotypes and serogroups), in rainbow trout. Notably, no mortality occurred in any *F. psychrophilum* exposed vaccinated fish throughout the experiments, in stark contrast to mock-vaccinated *F. psychrophilum* exposed fish, which experienced clinical BCWD and high mortality. Encouragingly, all three vaccines yielded 100% relative percent survival, and also substantially reduced the risk of *F. psychrophilum* infection in fish that were analyzed 27 days after exposure to the bacterium.
   - Developed and tested the protective efficacy of an experimental BCWD trivalent experimental vaccine in rainbow trout. Once again, no mortality occurred in any *F. psychrophilum* exposed vaccinated fish throughout the experiments, in contrast to mock-

vaccinated *F. psychrophilum* exposed fish, which experienced clinical BCWD and high mortality. This vaccine also yielded 100% relative percent survival, and *F. psychrophilum* infections were not detected in any vaccinated fish despite being prevalent in mock-vaccinated fish that were sampled at the same time.

- Generated pivotal protective efficacy data for four different vaccines experimental BCWD vaccines, which have now set the stage for additional testing and optimization. Notably, two of these vaccine preparations also provided protection against BCWD despite vaccinated fish suffering from a non-infectious co-morbidity (nephrocalcinosis).

Nisha Shrestha, the Michigan State University PhD student (Major Professor, Dr. T. Loch) who led the *Flavobacterium psychrophilum* characterization, virulence, and vaccine experiments in this USDA-NIFA NCRAC funded project, observes the experimental rainbow trout (*Oncorhynchus mykiss*) that she hatched from eggs.

Outcomes/Impacts

- This USDA-NIFA NCRAC funded study had sizeable impacts that enhanced fish health (a priority need voiced by producers in USDA-NIFA's North Central Region) and improved productivity in the aquaculture industry. To our knowledge and prior to this project, a Regional Aquaculture Center (RAC) had not invested heavily in supporting a region-wide Outreach Veterinarian with strong expertise in fish health and aquaculture and with a primary mission of being available and accessible to help producers solve and prevent recurrent and emerging fish health needs, including by working with already existing veterinary and fish health expertise in various NCR states. Importantly, the two-year investment by NCRAC to do so in this project paid substantial dividends and was leveraged

into numerous additional fish health resources that are and will continue to benefit fish producers into the future.

- This USDA-NIFA NCRAC funded project enabled the creation of a first-of-its kind online interactive tool for aquaculture producers to evaluate site-specific best management practices for fish health. The tool will provide long-term impact beyond the life of the project, serving as a resource for fish farmers, extension specialists, and fish health professionals in the region. In addition, the underlying framework on which the tool is built can be leveraged to create similar interactive experiences for farmers across regions and production sectors.
- This USDA-NIFA NCRAC funded study had a sizeable impact for veterinarians seeking additional training in aquatic animal medicine, as well as for veterinary students, graduate students, and undergraduate students interested in aquatic animal health. In addition to knowledge and training being shared during workshops and presentations (which far surpassed the number and scope we had originally proposed), this USDA-NIFA NCRAC funded research afforded multiple veterinary and graduate students the invaluable immersive experience of visiting NCR fish farms (notably for these students, a first), as well as experience and training in interacting with fish farmers and participating in devising strategies to help solve "real-world" limitations to fish health and farm productivity. The impact these opportunities have had on the students involved in this project cannot be understated, and is directly solving an industry stated need of more knowledgeable and experienced fish health expertise that is available to industry now and in the future.
- This USDA-NIFA NCRAC project provided funds that were leveraged to create a Regional Aquaculture Veterinary Outreach position at MSU. Dr. Kebus has provided regional leadership and coordination of fish health efforts for fish farmers based on their requests for help. See MSU CVM website on Aquaculture Veterinary Outreach for Fish Farmers and Veterinarians https://cvm.msu.edu/research/faculty-research/infectious-disease/aquaculture-outreach
- This USDA-NIFA NCRAC funded study yielded new knowledge resulting from the multi-year regional surveillance for *Flavobacterium psychrophilum* (cause of bacterial coldwater disease) that, to our knowledge, is the largest ever of its kind in the USA. Indeed, the extensive library of flavobacterial isolates that have been recovered, identified, typed, and cryopreserved in this study is serving as an invaluable resource for enhancing fish health in the NCR (i.e., by guiding and being used in vaccine preparations against a top disease facing trout and salmon producers). Likewise, new knowledge generated in this USDA-NIFA NCRAC funded project has highlighted that some facilities within the NCR are battling *F. psychrophilum* variants that are similar or identical to those from other regions of the USA, whereas others face losses caused by different variants that are unique to the region, or in some cases, unique to the state/farm where they were recovered. Notably, this important information will allow fish health specialists and aquaculture stakeholders to boost fish health and productivity in the NCR, including through the development of vaccines that account for this variation (see below).
- This USDA-NIFA NCRAC funded project directly supported the development and laboratory testing of four experimental killed vaccines (i.e., bacterins) against bacterial coldwater disease (BCWD), a top disease impediment to trout and salmon production in the USA. Promisingly and despite being experimentally exposed to high concentrations (> 100,000,000 bacteria/ml) of the bacterium causing this disease, not a single vaccinated rainbow trout died from BCWD in a series of three independent, multiple month laboratory experiments (in contrast to mock-vaccinated fish that were identically exposed and experienced severe disease and mortality). With this baseline of exceptionally promising

data, we anticipate being able to equip trout and salmon producers with tools that effectively prevent BCWD in the short to medium term.

Targeted Audience

The primary audience for this USDA-NIFA NCRAC funded project are fish farmers/producers in the North Central Region; the fish farming industry at large (but especially trout/salmon producers); anyone interested/involved in raising fish in hatcheries/aquaculture facilities; aquatic veterinarians and aquatic animal health professionals; students aspiring to become producers, veterinarians, aquatic animal health professionals, and/or researchers; researchers; and fishery management agencies. The assembled team has strong ties to these audiences, and we have been actively capitalizing upon already existing and newly formed relationships and collaborations for two-way information exchange and numerous training and education opportunities as a result of this USDA-NIFA NCRAC funded project.

Recommended Follow-Up Activities

- Additional studies to capitalize upon the success of the experimental BCWD vaccines developed herein, particularly in the vein of assessing multiple immunization routes, administration, and associated preparation procedures
- Equip NCR producers with additional information, knowledge, and access related to vaccination options for farmed fish
- Long-term sustainability of the interactive Best Management Practices tool developed herein
- Continued NCR producer access to veterinarians that are well-versed in aquatic animal health and fish farming

Partnerships

Mr. Marvin Emerson, Crystal Lake Fisheries, Missouri
Dr. Steven Summerfelt, Superior Fresh, LLC, Maryland

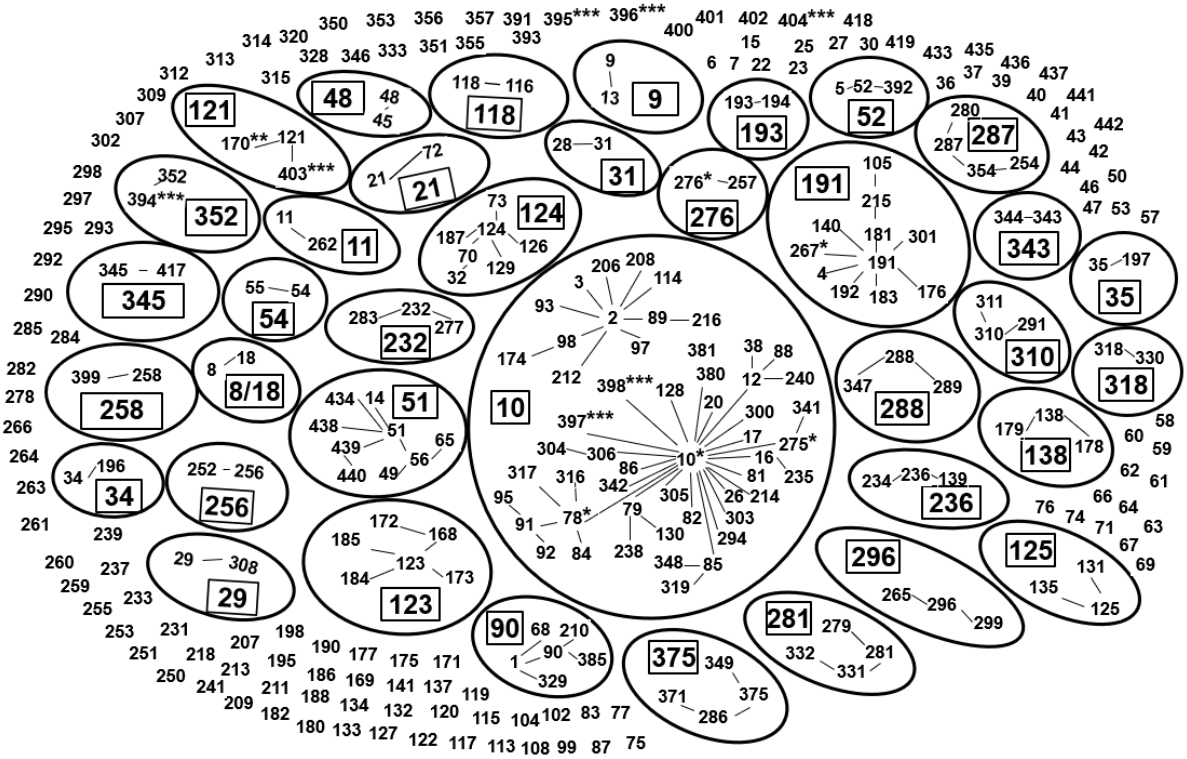


Figure 1. eBURST diagram depicting inferred genetic relatedness (as determined by multilocus sequence typing; MLST) of *Flavobacterium psychrophilum* isolates typed in the present study (n=109) compared to previously typed isolates in the pubMLST database (n=>1500). Asterisks (*) denote sequence types (ST) that include isolates recovered in this study but were previously described and reported in the USA. Double asterisks (**) denote STs recovered in this study for the first time in the USA, but previously reported in Europe. Triple asterisks (**) indicate newly identified STs that have not been reported previously. Clonal complexes (CC) are defined as groups of sequence types (ST) connected by single locus variant (SLV) links and are encircled. Each CC is named after the most likely founding ST (i.e., ST with the greatest number of SLVs). If multiple STs have the same number of SLVs within a CC, the CC is named after the ST with the largest number of isolates. If both STs have the same number of isolates, the CC is named after the earliest identified ST. The founding ST of each CC appears within a box.

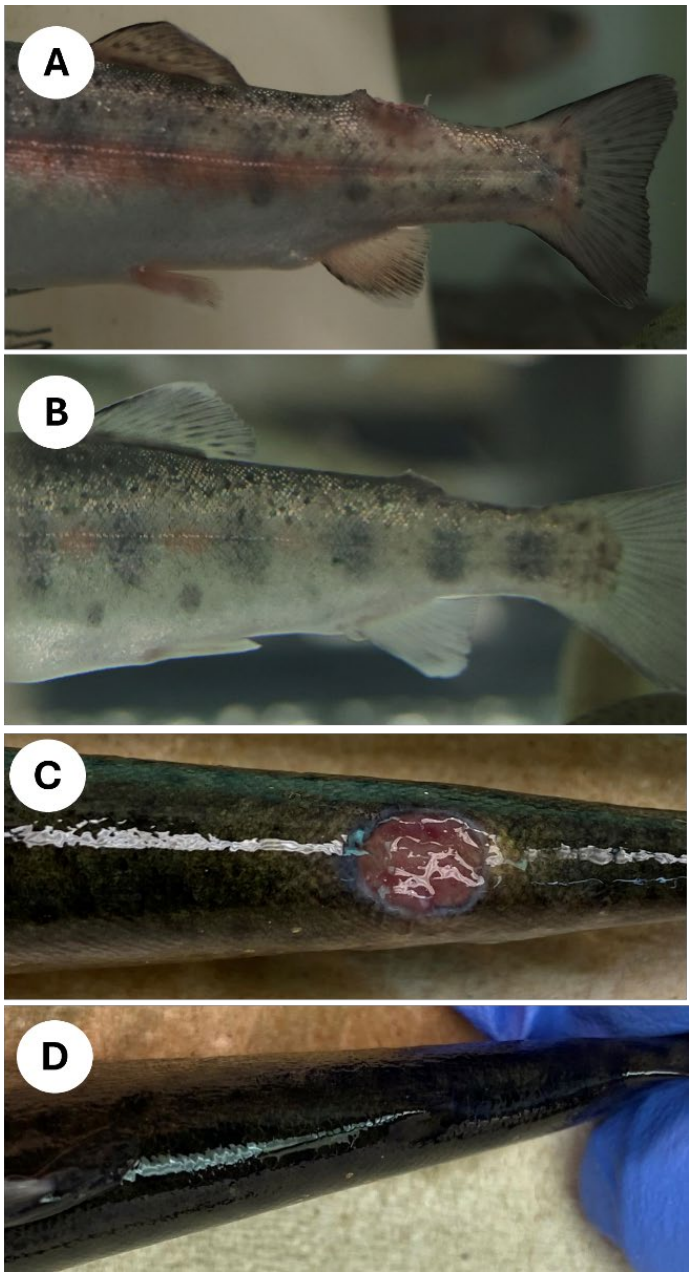


Figure 2. Images of live (A, B; 10 days post-bacterial exposure) and freshly euthanized (C, D; 26 days post-bacterial exposure) rainbow trout that were mock-vaccinated (A, C) or vaccinated (B, D) with one of our team's experimental killed *F. psychrophilum* vaccine preparations and subsequently exposed to live *F. psychrophilum* via bath exposure after having been adipose fin-clipped. Note the active ulceration, swelling, and hemorrhage at the fin clip site in mock-vaccinated fish (A, C) compared to the healing (B) and nearly completely healed (D) clip sites in vaccinated fish. Notably, *F. psychrophilum* was recovered from the internal organs and external lesions of some mock-vaccinated fish, but not from any fish that were vaccinated with these new preparations.

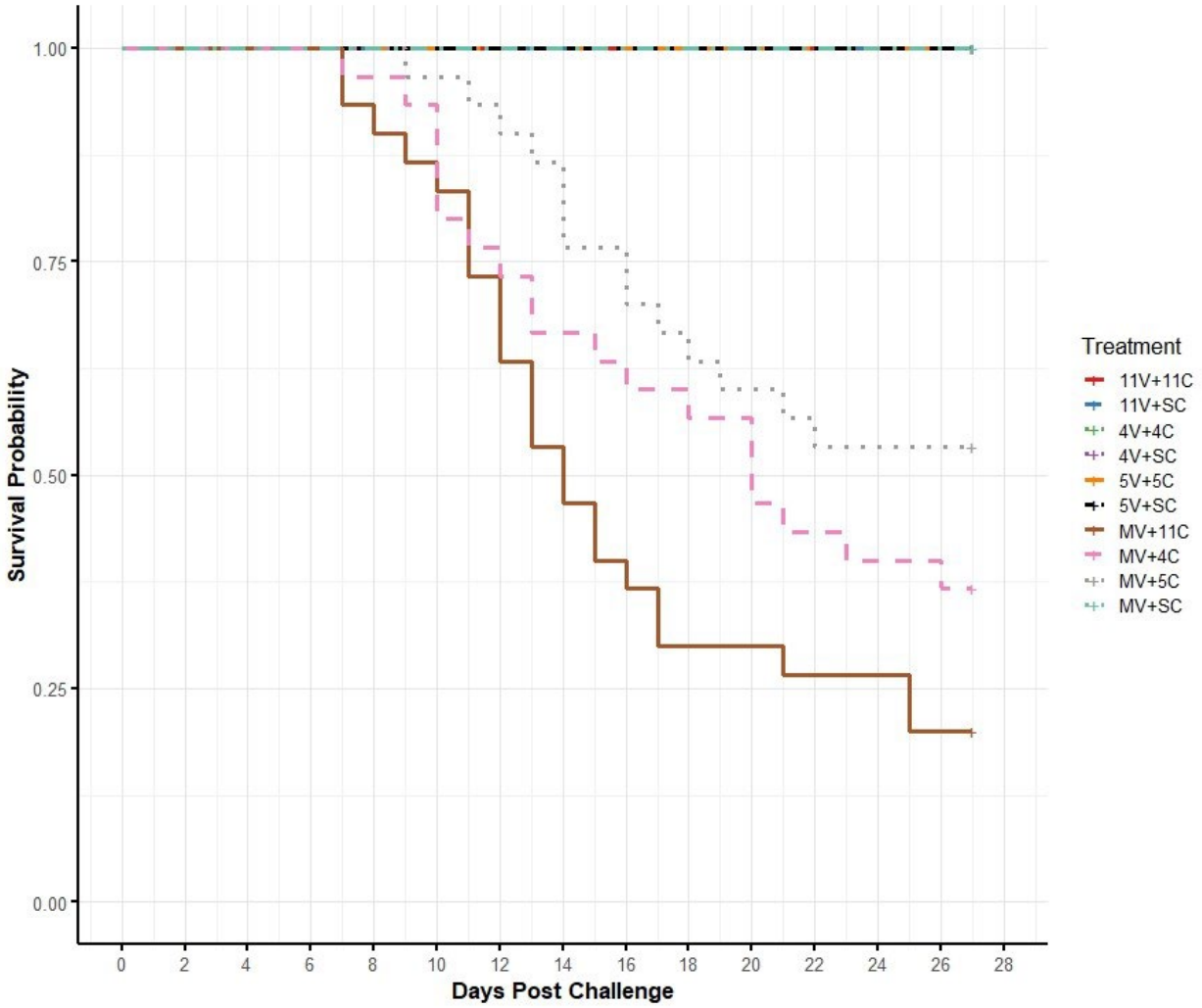


Figure 3. Kaplan-Meier survival curves of rainbow trout vaccinated (Monovalent vaccination) and challenged with *F. psychrophilum*. M= mock-vaccinated, V= vaccinated, C= *F. psychrophilum* challenged, S=0.65% saline solution. 4, 5 and 11 are numbers given to different strains of *F. psychrophilum*. Survival was monitored for 27 days post-challenge.

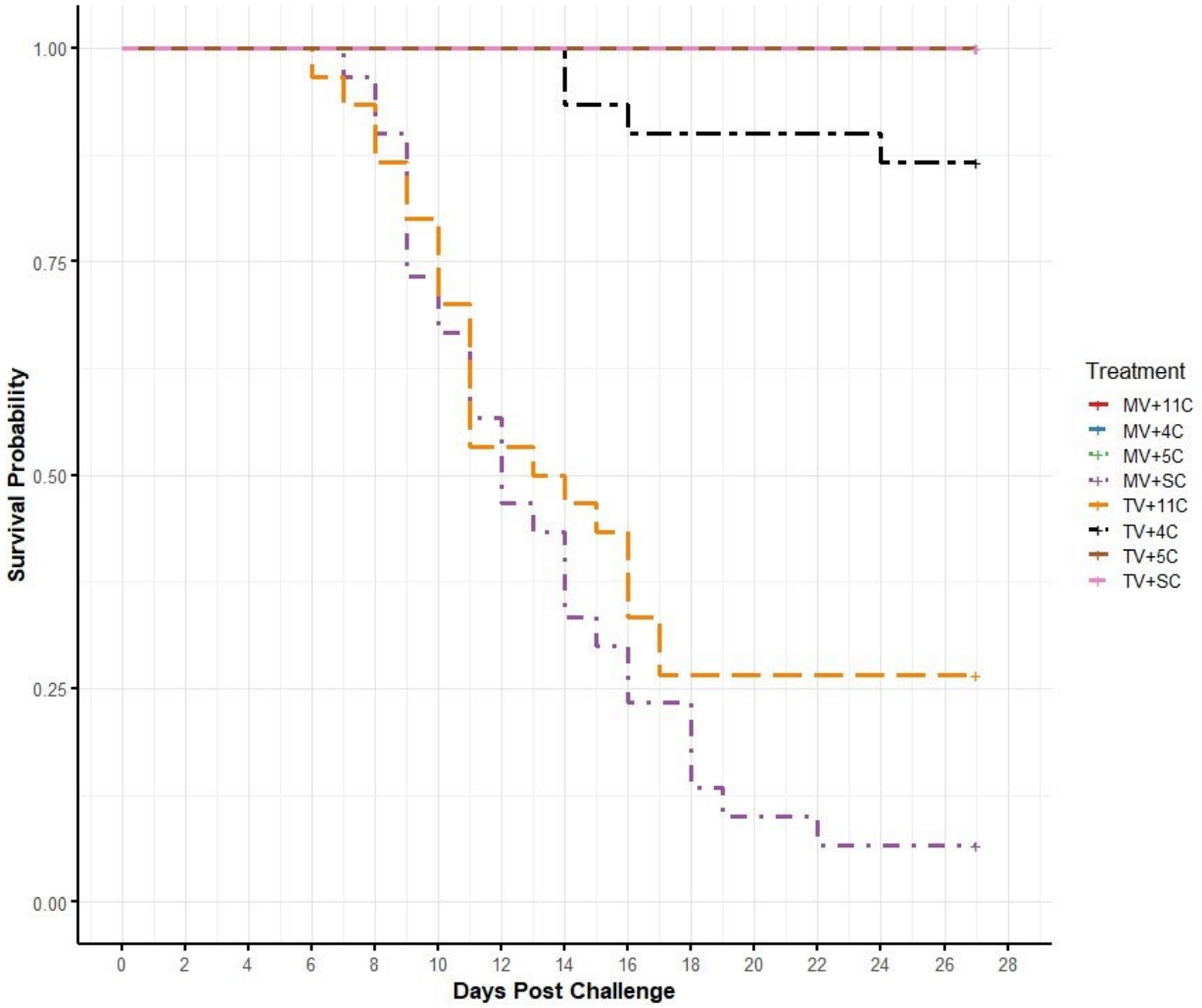


Figure 4. Kaplan-Meier survival curves of rainbow trout vaccinated (trivalent vaccine) and challenged with *F. psychrophilum*. M= mock, T= Trivalent, V= vaccinated, C= challenged, S= 0.65% saline solution. 4, 5 and 11 are numbers given to different strains of *F. psychrophilum*. Survival was monitored for 27 days post-challenge. Numbers 4, 5, and 11 are numbers given to different strains of *F. psychrophilum* used in this experiment.

Project Title: Intensification of First Year Largemouth Bass (*Micropterus Salmoides*) Using Alternative Pond-Based Production Systems [Termination Report]
Total Funds Committed: $328,367
Initial Project Schedule: September 1, 2021-August 30, 2022 [Extended to August 31, 2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: James Garvey, Southern Illinois University-Carbondale; Robert Rode Purdue University; Paul Brown, Purdue University; Karolina Kwasek, University of New Hampshire
Extension Liaison: Paul Hitchens, Southern Illinois University-Carbondale
Industry Liaison: Stacey Sisk, Big House Fish Farm

Relevance: The benefit to the industry is to raise age-0 largemouth bass fry to fingerling size at maximum production. This project will provide us with data that we can use to compare production practices between traditional culture ponds, pond-side tank culture systems, and split-ponds for largemouth bass in research ponds at Purdue University and SIU-Carbondale. Largemouth bass farmers in the Midwest will have the opportunity to visit the research sites and the on-farm demonstration to learn about whether or not these production systems may be worth adopting on their farms. These systems could provide an opportunity for largemouth bass farmers to purchase smaller fingerlings from hatcheries. Additionally, farmers of other species can have the opportunity to learn about other potential production practices.

Response: Pond-side tanks and split ponds showed that age-0 largemouth bass raised in intensive culture produce more biomass than in whole ponds.

Results: Five distinct objectives were pursued in this project:

1. To evaluate two alternative pond-based production systems (split ponds and pond-side tank culture) in the Midwest on largemouth bass, *Micropterus salmoides*, quantified production parameters.
   At the conclusion of Year-1, the only significant differences in split-pond vs. full pond comparisons existed within the coefficient of variation (CV) of final weight and CV condition factor (CF). Fish reared in the full ponds showed a significantly higher CV in both final weight and CF compared to the split-ponds. In Year-2, no significant differences were observed in the final weight, length, or CF between the three tested systems. The full ponds showed a significantly higher CV of final length than the split-ponds and tanks, and a significantly higher CV of final weight compared to the tanks. There were no significant differences in the CV of CF between groups. Additionally, there were no significant differences between groups in the SGR, production efficiency, and survival. In both years, the full ponds showed a significant deviation from homogeneous variance in total length. This suggests the dispersal and variation of fish lengths was significantly different between individual full ponds. Meanwhile, homogeneity of variance was not rejected for split-ponds or tanks, suggesting the size distribution among individual split-ponds and tanks was consistent. Overall, both split-ponds and pond-side tanks exhibited more uniform growth in producing LMB. Pond-side tanks, although performing the best at maintaining more uniformly sized fish, produced fish of smaller size. These results suggest that pond-side tanks are likely not viable, as we designed and implemented them, for rearing LMB as food fish. With improved size homogeneity and comparable production, split-ponds showed promise as an alternative pond-based production system for rearing LMB.

Asyeh Sohrabifar, masters student in civil engineering at Southern Illinois University, runs exclusion netting around s split-pond experiemental unit in Spring 2025. Netting was needed to reduce predation by mammals and birds on fingerling largemouth bass.

2. To investigate and compare changes in water quality and the aquatic food web in the pond-based production systems.
   Mean values across the experiment showed split-ponds to have higher DO, pH and conductivity, as well as lower temperature compared to other systems. Full ponds mean values were highest among systems for ORP, N-ammonia, chlorophyll, and TOC and lowest for nitrite and pH. Tank mean values were highest for nitrite and lowest for chlorophyll, ORP, DO, un-ionized ammonia, and N-ammonia. Of the 11 variables assessed within models for "between system" comparisons, only N-ammonia and nitrate are suggested not to be significantly influenced by system-type. Compared to both split-ponds and tanks, full ponds showed a negative influence on nitrite and conductivity and a positive influence on ORP and TOC. Compared only to split-ponds, full ponds additionally showed a negative influence on un-ionized ammonia, DO and pH with a positive influence on temperature. Overall, both split-pond and tank systems more consistently exhibited nitrogen profiles indicative of effective nitrification than full ponds. Split-ponds maintained more desirable consistency across the experimental period for DO, temperature, and pH compared to tanks and full ponds.

Asyeh Sohrabifar stands next to two experimental fingerling largemouth bass from the "open pond" treatment. Fingerlings were started at identical sizes at the start of the experiment. The size disparity between the fish is typical of what occurs in traditional largemouth bass farming. Significant losses occur as large bass consume smaller ones. Both split pond and side tank treatments reduce these size differences and led to higher yield of fingerlings.

3. To investigate the effect of the two-alternative pond-based production methods (split ponds and pond-side tank culture) on LMB response to stress.
   The effect of these alternative production methods on stress in LMB was unable to be analyzed as part of this project. Gill, blood, and whole-body samples were collected from both years; however, the mishandling of samples by the shipping company led to a complete loss of usable samples.

4. To conduct an on-farm extension demonstration of the pond-side tank culture system.
   A pond-side aquaculture demonstration was conducted at Purdue University, with participation from fish farmers in Fall 2023. A second pond-side system is being built at Big House Farms in Carbondale, IL and should be ready for a demonstration in early Spring 2026.

5. To immediately disseminate results to industry via final termination report to NCRAC.
   Dissemination of project results were initiated by presenting relevant findings at two conferences: 2025 World Aquaculture Society (New Orleans) and 2025 American Fisheries Society (San Antonio). Additionally, two manuscripts have been prepared and will be submitted to peer-reviewed journals. Facility tours (upon request) have allowed local farmers and other officials within fisheries/aquaculture to examine the infrastructure and ask questions about the experiment. Further plans to disseminate this study's findings exist by methods of social media and other electronic media.

Koaw Zacek, PhD student at Southern Illinois University, presents project research results at the 2025 World Aquaculture Society in New Orleans, LA.

Outreach Overview: Facility tours (upon request) have allowed local farmers and other officials within fisheries/aquaculture to examine the infrastructure and ask questions about the experiment. Further plans to disseminate this study's findings exist by methods of social media and other electronic media.

Impacts: Split-pond systems as alternative pond-based production systems may be a viable way for farmers to produce LMB of more uniform size compared to traditional full pond systems while not sacrificing biomass production. Improved size-homogeneity decreases intracohort cannibalism, a problem faced by any farmer producing cannibalistic fishes, which includes LMB. Additionally, the split-ponds showed the potential for a more efficient nitrogen cycle and greater consistency of physiochemical conditions for LMB. Ultimately, the split-ponds demonstrated in this study have the potential to be implemented on existing LMB farms, and improve uniform production of LMB as a food fish.

Targeted Audience: Farmers are the intended audience as we seek to learn more about the production feasibility of pond side tank culture and split-ponds using smaller feed habituated largemouth bass.

Recommended Follow-Up Activities:

- As LMB reared as food fish will require more than one grow out season, further studies should examine comparisons between maintaining cohorts in split-ponds for both growing seasons vs. cohorts reared in split-ponds for the first growing season and then moved to full ponds for the second growing season. Examination should focus on whether size homogeneity is maintained across both growing seasons.

- For both split-pond and pond-side tank systems, larger scale infrastructure (especially bass-containing areas) should be utilized to mimic more closely what a typical farmer would use.

With replicate treatments, different stocking densities could be utilized to determine a more optimal stocking density within these system types.

- Economic analysis should be conducted to determine the cost of large-scale implementation of the split-pond systems and the value added through the improved size uniformity and water quality.

Project Title: Sustainable Aquaculture: Development of New Quantitative Metrics for Use in Marketing Aquaculture Products [Termination Report]

Total Funds Committed: $127,131
Initial Project Schedule: September 1, 2021-August 31, 2023 [Extended to August 31,2025]
Current Project Year: September 1, 2024-August 31, 2025
Participants: Paul Brown, Purdue University; Jen-Yi Huang, Purdue University; Rob Anex, University of Wisconsin; Brian MacGowan, Purdue University
Extension Liaison: Matthew Smith, The Ohio State University; Herbert Quintero, The Ohio State University
Industry Liaison: Dan Mosier, II, Kansas Department of Wildlife, Parks & Tourism

Relevance: Consumers are seeking low environmental impact foods, but quantitative data are lacking.

Response: The project is conducting LCA of multiple aquaculture operations in the North Central Region.

Results: One objective is being pursued in this project:
Develop quantitative metrics from existing aquaculture farms in the NCR and compare these values to other food production systems producing competing protein foods.

Purdue student working on Sustainable Ag Project

The goals of this LCA study was to assess the cradle-to-market environmental sustainability of existing fish farms in the NCR. This model provides verified and quantified values of the environmental impacts associated with the targeted system/species combinations. The results obtained also help identify the components of the analyzed aquaculture operations that contribute most to the environmental impacts (i.e. hotspots) for further improvement.

Seven aquaculture operations in the North Central region (NCR) were contacted and invited to participate in developing the LCA data. Five responded positively to the initial invitation and provided sufficient data to complete the LCA analysis. The five farms are a pond operation producing yellow perch (*Perca flavescens*), a pond operation producing largemouth bass (*Micropterus nigricans*), an indoor RAS operation producing barramundi *(Lates calcarifer*) a yellow perch farm raising fish in aquaponics systems, and a raceway operation producing rainbow trout (*Oncorhynchus mykiss*).

We acquired a complete life cycle inventory (LCI) of the 5 farms. The five farms evaluated in this study included a barramundi farm in Indiana, a rainbow trout farm in Wisconsin, a yellow perch farm in Ohio, a largemouth bass farm in Illinois, and a yellow perch aquaponic operation in Ohio. For all farms, an approximate composition of the feed was used based on the data provided by each of the farm managers, since the complete formulation of the feed from commercial mills is confidential information. Fish fingerlings used in the different farms were purchased from fish hatcheries, except for the rainbow trout and the yellow perch pond farms, where they hatch their own fish.

The operational data of all the fish farms studied were provided by the farm. The barramundi farm in Indiana produces 7,882 kg per cycle, the rainbow trout farm in Wisconsin produces 200 kg per cycle, the yellow perch aquaponic farm in Ohio produces 453.6 kg per cycle, the yellow perch pond farm in Ohio produces 3409 kg per cycle, and the largemouth bass farm in Illinois produces 45,454 kg per cycle.

The barramundi farm is an indoor production facility using a recirculating aquaculture system (RAS) with a total capacity of 378.5 m^3. The rainbow trout farm operates outdoors using 56 flow-through raceways with a total area of 32.4 hectares. The indoor yellow perch farm operates using an aquaponic recirculating system with a total capacity of 49,205 l. The yellow perch aquaculture farm operates four 1-acre and two 0.5-acre ponds for a total capacity of 5 surface acres of water. The largemouth bass farm operates using seven outdoor ponds for a total capacity of 72,846 m^3 (59.1 acre-feet) of water.

The midpoint environmental impact was used to analyze the environmental performance in this study, using the TRACI v2.2 Midpoint E v1.02 methods. The TRACI v2.2 method provided eighteen midpoint indicators, but this study focused on ten indicators, including ozone layer depletion potential (OLDP, kg CFC-11 eq), global warming potential (GWP, kg CO_2 eq), smog (kg O_3 eq), terrestrial acidification potential (TAP, kg SO_2 eq), freshwater eutrophication potential (FEP, kg P eq), human carcinogenic (CTUh), human non-carcinogenic (CTUh), human respiratory effects (kg PM2.5 eq), aquatic ecotoxicity (AE, CTUe), and fossil fuel depletion (MJ surplus).
The LCA of barramundi culture revealed notable environmental impacts across several categories. Electricity usage was a dominant contributor in multiple impact categories, including ozone depletion (71.19%), carcinogenic effects (62.68%), respiratory impacts (59.64%), and fossil fuel depletion (55.89%). Feed production was another key hotspot, contributing heavily to categories such as global warming (49.31%), smog formation (46.19%), acidification (71.02%), eutrophication (74.63%), and ecotoxicity (66.36%).

The LCA of rainbow trout culture highlighted significant contributions to various impact categories, with electricity consumption and fish feed production emerging as the primary contributors. Ozone depletion was primarily influenced by electricity use (97.8%). Similarly, global warming potential (GWP) was heavily impacted by electricity (73.8%) and fish feed

production (25.6%). Smog formation was largely influenced by electricity usage (59.6%). Acidification impacts were almost equally divided between electricity (50.2%) and fish feed production (48.8%). Eutrophication was almost entirely attributed to the production of rainbow trout (99.3%). Carcinogenic effects were predominantly caused by electricity usage (88.4%), while fish feed contributed 11.6%. Non-carcinogenic effects were primarily driven by fish feed production (67.6%). Respiratory effects were overwhelmingly linked to electricity consumption (86.6%). Ecotoxicity was largely attributed to electricity (63.9%) and fish feed (35.9%). Fossil fuel depletion was dominated by electricity (89.6%).

The LCA of yellow perch aquaponics farming revealed that electricity consumption is the predominant contributor across multiple impact categories. It accounted for 99.75% of ozone depletion, 96.27% of global warming, 90.57% of smog formation, and 91.24% of acidification. It also contributed 98.49% to carcinogenics, 98.48% to respiratory effects, 94.65% to ecotoxicity, and 98.43% to fossil fuel depletion.

Results of yellow perch farming in the NCR revealed that fish feed and electricity significantly contribute to the environmental impact. Global warming impacts were primarily driven by electricity use (55.94%) and feed production (44.06%). Smog formation and acidification impacts displayed similar trends, with feed accounting for 63.81% and 66.78% of the impacts, respectively. Carcinogenic and respiratory effects were heavily influenced by electricity use, contributing 75.20% and 74.74%, respectively. Non-carcinogenic and fossil fuel depletion impacts were largely attributed to fish feed, with contributions of 81.16% and 21.88%, respectively, and electricity production contributing 18.84% and 78.12%, respectively. Finally, ozone depletion and ecotoxicity impacts were primarily associated with electricity use (94.64%) and a combination of fish feed (54.01%) and electricity (44.92%), respectively.

Feed, electricity, and other production inputs were the main contributors to the environmental burden of producing 1 kg of largemouth bass. Ozone depletion was largely driven by electricity consumption, which accounted for 84.9% of the total impact, while the remaining 15.1% was attributed to feed production. Similarly, GWP was dominated by feeds, contributing 73.2% of the total emissions, with electricity accounting for the remaining 26.8%. The smog formation impact category revealed a similar trend, with feeds responsible for 82.3% of the total impact and electricity contributing 17.7%. Acidification impacts were also dominated by feeds, which accounted for 88.3%, with electricity contributing 11.7%. Eutrophication impacts were primarily associated with largemouth bass farming as the primary contributor (87.1%) due to nutrient runoff and waste from aquaculture activities. Carcinogenic impacts were split between electricity (50.7%) and feeds (49.3%). Non-carcinogenic impacts were heavily influenced by feed production, contributing 93.3%, with electricity accounting for only 6.7%. Respiratory effects, ecotoxicity, and fossil fuel depletion further highlighted the dominance of feeds as a key driver of environmental impacts. For respiratory effects, feeds contributed 55.6%, with electricity at 44.4%. In ecotoxicity, feeds dominated at 80.2%, while fossil fuel depletion shows a closer split, with feeds at 45.5% and electricity at 54.5%.

These aquaculture metrics were compared to conventional protein-producing food systems such as chicken, pork, and beef. All aquaculture farms evaluated displayed lower impacts than swine production in GWP. When comparing acidification and respiratory effects, aquaculture species again had lower values. Swine production had notably high acidification potential (3.01 kg SO_2 eq), while values for yellow perch (0.021 kg SO_2 eq) and largemouth bass (0.059 kg SO_2 eq) were substantially lower. Similarly, aquaculture had lower respiratory effects in terms of particulate matter formation impacts compared to swine (0.0808 kg PM2.5 eq), with yellow perch and

largemouth bass generating only 0.0025 and 0.0041 kg PM2.5 eq, respectively. In the toxicity-related impact categories, swine production had notably higher values than most aquaculture systems. For instance, carcinogenic effects from swine exhibited 0.000217 CTUh, compared to 1.19×10^{-7} CTUh for largemouth bass and 8.27×10^{-8} CTUh for yellow perch. Similarly, swine exhibited higher non-carcinogenic impacts (0.00124 CTUh) and ecotoxicity (2.65 CTUe). Overall, while aquaculture systems exhibited elevated impacts in certain categories (e.g., smog and energy-related metrics), they demonstrated lower burdens in climate-related and toxicity categories compared to pork. Chicken consistently outperformed all other protein sources across most impact categories, which is in line with broader literature citing high production efficiency and streamlined supply chains in poultry systems. These results highlight the potential of aquaculture as a sustainable protein option in temperate climates. However, optimizing energy use (e.g., integrating renewable energy sources), diets, and improving nutrient management remain critical to minimizing environmental trade-offs in future system designs.

Outreach Overview

This effort produced the first LCA of multiple aquaculture farms in the US. The data generated indicated that electricity and feeds were the most significant contributors to environmental impact. Data also provided marketing opportunities for aquaculture farms, specifically the lower global warming potential of all aquaculture operations when compared to swine production. Future studies focused on alternative energy use and sustainable feeds can further reduce the environmental impact of aquaculture and provide additional marketing opportunities for aquaculture. A popular article is in development for publication in either Aquaculture Magazine or World Aquaculture.

Targeted Audience

- Fish farmers who are seeking an objective and quantitative metric for marketing the sustainability of their products.
- New producers who are sorting through options of system/species combinations for their operations.
- Consumers desiring sustainable foods.

Outcomes/Impacts

Multiple aquaculture production systems and species were evaluated using LCA. Regardless of the systems or species, electricity and feeds were the environmental hotspots (i.e., factors contributing to environmental degradation). Those two areas should become focal points in future research focused on reducing the environmental impacts of aquaculture. Global warming potential of all aquaculture operations was lower than published values for swine production and offers a marketing opportunity for aquaculture farms.

Recommended Follow-Up Activities

Future studies should focus on alternative energy sources for aquaculture (wind, solar, anaerobic digestors) as sources of energy, as well as local grid networks. Dietary research should focus on sustainable feeds by incorporating an additional metric into formulation approaches (e.g., global warming potential).

Products Developed/Students Supported

Papers Presented

Nelson, E. 2024. NCRAC and GLAC, Educating through aquaculture. Michigan Aquaculture Association Annual Meeting. Clare, MI.

Schrank, A.J. 2024. Developing an aquaculture literate public through youth and adult engagement. Aquaculture America, San Antonion, TX.

Jescovitch LN. 2024. Mi Fresh Fish: A Fisheries' Consumer Education Marketing Campaign. Meeting of the US Aquaculture Society. San Antonio, TX.

Hebert E., B. J. Southwell, B. I. Evans and D. D. Wright. 2024. Avoiding metal toxicity in closed loop aquaponics. Aquaculture America USAS Annual meeting, San Antonio TX.

Nelson, E. B. I. Evans. 2024. Creating workforce pathways by educating youth through aquaculture. Aquaculture America USAS Annual meeting, San Antonio TX.

Smith KT, Jescovitch LN, Nelson K, Evans BI, Schrank AJ. 2023. What do consumers know about aquaculture? Survey findings from those who educate consumers. Annual Meeting of the US Aquaculture Society. New Orleans, LA.

Jescovitch LN, Smith K, Nelson K, Evans BI, Schrank AJ. 2023. What do consumers know about aquaculture? Survey findings from those who educate consumers. Annual Meeting of the US Aquaculture Society. New Orleans, LA.

Jescovitch LN, Seilheimer T, Willis T, Shambach A, Schrank AJ, and the GLAC team. 2023. Fortifying a resilient seafood supply chain in the Great Lakes region. Annual Meeting of the US Aquaculture Society. New Orleans, LA.

Evans, B. Wright, D.D. Southwell, B.J. Hebert, E . 2023. Accumulation of metal ions in closed loop aquaponics. Aquaculture America USAS Annual meeting, New Orleans LA.

Evans, B., Nelson, E. 2023. Aquaculture workshops: teaching the teachers, Aquaculture America USAS Annual meeting, New Orleans LA.

Evans, B., Nelson, E. 2023. Examples from the Classroom: K-12 Teaching Resources in Aquaculture North Central Regional Aquaculture Conference, Eau Claire, WI.

Evans, B., Nelson, E. 2023. Designing and Building Mini-systems: A hands on Activity. North Central Regional Aquaculture Conference, Eau Claire, WI.

Schrank, A.J. and Smith, K. 2023. Development of consumer education materials on seafood and aquaculture. North Central Regional Aquaculture Center conference, Eau Claire, WI.

Evans B.I., E. Nelson and C. Hartleb. 2022. Educational supply lines for developing an aquaculture workforce. World Aquaculture Society meeting, San Diego, CA.

Nelson, E. and B.I. Evans. 2022. Creating workforce pathways by educating youth through aquaculture. World Aquaculture Society meeting, San Diego, CA.

Brown, P.B. and J.-Y. Huang. 2025. Sustainability in the 21st Century and the Role of Aquaponics. Aquaponics Association Annual Conference, College Park, MD.

Brown, Paul B., Jemuel Doctolero, Aya Hussain, Jen-Yi Huang, Thomas To-Hung Tsui, Rob Anex, Dan Mosier and Herbert Quintero. 2025. Sustainable aquaculture: development of new quantitative metrics for use in marketing aquaculture products. USDA North Central Regional Aquaculture Center Annual meeting. Kansas City, MO.

Zhai SW, Lu X, Yang S, Binkowski FP, Deng DF. Optimal Feeding Rates for Growth Performance, Nutrient Retention, and Heat Shock Protein 70 Expression in Fingerling Yellow Perch (*Perca flavescens*). Animals (Basel). 2025 May 19;15(10):1465. doi: 10.3390/ani15101465

Kebus M#, Loch T. Strengthening the Aquaculture Veterinary Workforce by Identifying Core Competencies Needed and Providing Targeted Training Workshops. Invited virtual presentation at the Michigan Department of Agriculture and Rural Development-Animal Industry Division Meeting, Aquaculture Advisory Committee, October 23, 2025.

Kebus M#, Loch T. Strengthening the Veterinary Workforce. Invited presentation at the American Association of Fish Veterinarians 2025 Annual Conference. Riverside, New York October 15, 2025.

Kebus M#. Strengthening Aquaculture Veterinary Medicine Through Outreach. Poster presentation at MSU, College of Veterinary Medicine Phi-Zeta Event, East Lansing, Michigan, August 15, 2025.

Shrestha N, Kebus M, Smith M, Phelps N, Lennox S, Shavalier M, Knupp C, Pilarski F, Loch TP#. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Invited Presentation at the Great Lakes Fishery Commission – Great Lakes Fish Health Committee Meeting, Duluth MN, August 2025.

Lennox S#. Development and Evaluation of Novel Tools to Reduce Vertical Transmission of *Flavobacterium psychrophilum* and Enhance Prevention of Bacterial Coldwater Disease. Oral Dissertation Defense, Presented at Michigan State University, East Lansing, MI, July, 2025.

Kebus M#, Loch T. Strengthening the Fish Farm Veterinary Workforce, Fish Farm Biosecurity, and Enhancing Aquatic Animal Disease Preparedness and Response in the North Central Region. Invited presentation at the Eastern Fish Health Workshop, Grand Rapids, Michigan, March 20, 2025.

Shrestha N#, Kebus M, Lennox S, Shavalier M, Knupp C, Pilarski F, Smith M, Phelps N, Loch T. Using genotype, molecular serogroup, and in vivo virulence as a road map for developing experimental bacterins against bacterial coldwater disease. Presented at the National Eastern Fish Health Workshop, Grand Rapids, MI, March, 2025.

Kebus M#, Loch T. Strengthening the Aquaculture Veterinary Workforce. Invited presentation at the Veterinary Services Aquaculture Health Session - Showcasing what we do for US quaculture,

Aquaculture Americas 2025, New Orleans, Louisianna, March 10, 2025.

Kebus M#, Loch T. Strengthening the Aquaculture Veterinary Workforce. Invited presentation at the in Innovative Veterinary Practices in Aquaculture Session, at Aquaculture Americas 2025, New Orleans, Louisianna, March 8, 2025.

Kebus M#. Peter Fritsch, WI Fish Health Case Study. Invited presentation at the Wisconsin Aquaculture Association Annual Conference, Marshfield, Wisconsin, February 21, 2025.

Kebus M#. NCRAC Fish Health Initiatives, Dr. Myron Kebus, Aquaculture Outreach Veterinarian, North Central Regional Aquaculture Center (NCRAC). Invited presentation at the, Missouri Aquaculture Conference, Kansas City, Missouri, February 7, 2025.

Kebus M#. Aquaculture Veterinary Outreach. Invited presentation at the Michigan Aquaculture Association Meeting, January 30, 2025.

Kebus M#. Fish Health Q&A. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025.

Kebus M#. Recent Disease Cases - Diagnosis, Treatment, and Prevention. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025.

Kebus M#. NCRAC Fish Health Initiative: Update and 2025 Activities. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025.

Kebus M#. Getting Started in Fish Farm Veterinary Medicine Part 1, 2. 3. Invited presentation at the Michigan Veterinary Conference, CE Session | Food Animal Track. Grand Rapids, MI. November 2, 2024.

Shrestha N, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP#. Uncovering the Geno- And Sero-Variation of *Flavobacterium psychrophilum* in the North Central Region of the USA to Guide Future Vaccination Approaches. Invited Presentation at the Great Lakes Fishery Commission – Great Lakes Fish Health Committee Meeting, Marquette, MI, August 2024.

Kebus M#. Broodstock Biosecurity. American Fisheries Society Fish Health Section Annual Conference, Invited presentation at the Continuing Education Workshop, Boise Idaho, August 2024.

Shrestha N#, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP. Uncovering the Geno- And Sero-Variation of *Flavobacterium psychrophilum* in the North Central Region of the USA to Guide Future Vaccination Approaches. Presented at the American Fisheries Society – Fish Health Section Virtual Summer Seminar Series, July 2024.

Shrestha N#, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP. Investigating the Geno- and Serotypic Diversity of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region of the USA. Presented at the Michigan Department of Natural Resources Fish Production Section Meeting,

Sault St Marie, MI, June 2024.

Kebus M#. How to Get Started in Aquaculture Veterinary Medicine. Invited presentation at the Michigan Veterinary Medical Association, Lunch and Learn Virtual Session, , May 2024.

Kebus M#. Biosecurity in Aquaculture. Invited presentation at the MSU, College of Veterinary Medicine, virtual PDI 636 clerkship on Aquatic Animal Medicine, May 2024.

Sacco L#, Haefner E, Loch T, Kebus M, Smith M, Phelps NBD. Best management practices for the health of your farmed fish: a new tool. American Fisheries Society – Fish Health Section Online Seminar Series. May 2024.

Shrestha N#, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP. Investigating the Geno- And Sero-Variation of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region, USA. Presented at the National 47th Eastern Fish Health Workshop, Gulfport, MS, March 2024.

Kebus M#, Loch TP, Phelps NBD, Smith MA. Fish Farmer Perspectives on Fish Health Management and Veterinary Involvement. Presented at the National 47th Eastern Fish Health Workshop, Gulfport, MS, March 2024.

Sacco L#, Haefner E. Best management practices for the health of your farmed fish. Wisconsin-Minnesota Aquaculture Conference. March 2024.

Kebus M#. What Steps to Take When Problems Arise. Invited presentation at the Wisconsin/Minnesota Annual Aquaculture Conference, Red Cliff, Wisconsin, March 2024.

Loch TP, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Fish health Survey in the North Central Region. Invited presentation at the Wisconsin/Minnesota Annual Aquaculture Conference, Red Cliff, Wisconsin, March 2024.

Shrestha N#, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP. Investigating the Geno- And Serotypic Diversity of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region of the USA. Presented in the "Flavobacterial Disease Management" Special Session at Aquaculture America, San Antonio, TX, February 2024.

Kebus M#, Shrestha N, Smith MA, Phelps N, Loch TP#. Veterinary Aquaculture Outreach in the North Central Region of the USA. Invited Presentation in the "Aquaculture Education, Extension, and Technology Transfer" Session at Aquaculture America, San Antonio, TX, February 2024.

Shrestha N#, Kebus M, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Nicolas P, Smith MA, Phelps N, Loch TP. Investigating the Geno- And Sero-Variation of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region, USA. Presented at the 19th Annual Michigan State University Department of Fisheries and Wildlife Graduate Student Research Symposium, East Lansing, MI, February 2024.

Loch TP#, Kebus M#, Smith MA, Phelps N, Shrestha N, Lennox SMG, Shavalier MA, Knupp CK, Pilarski F, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating outreach with the development of alternative disease prevention methods. Invited

Presentation at the USDA-NIFA NCRAC 2024 Annual Program Meeting, Ames, IA, February 2024.

Kebus M#. Advanced Fish Health Considerations. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 2024.
Kebus M#. Conducted Fish Health Roundtable Discussion. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 2024.

Kebus M#. Biosecurity. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 2024.

Shrestha N, Kebus M, Lennox SMG, Shavalier M, Knupp CK, Pilarski F, Smith MA, Phelps N, Loch TP#. Elucidating the Geno- & Sero-Variation of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region, USA. Invited Presentation at the Michigan Aquaculture Association, Clare, MI, January 2024.

Loch TP, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Invited presentation at the Michigan Aquaculture Association Meeting. Clare, MI, January 2024.

Kebus M#. Veterinary Aquaculture Outreach in the North Central (U.S.). Presented at the Annual Conference of the American Association of Fish Veterinarians, Springfield, Missouri, October 2023.

Loch TP#. Collaborative efforts to enhance aquatic animal health in the Great Lakes basin and beyond. Promotion and Tenure Seminar, Dept. of Fisheries & Wildlife and Dept. of Pathobiology & Diagnostic Investigation, Michigan State University, East Lansing, MI, October 2023.

Loch TP, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S., Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Presented at the U.S. Trout Farmers Annual Conference. Hershey, Pennsylvania, September 2023.

Shrestha N, Kebus M, Shavalier MA, Loch TP#. Michigan State University - Aquatic Animal Health Laboratory Research Updates. Invited Presentation at the Great Lakes Fishery Commission - Great Lakes Fish Health Committee Meeting, Grand Rapids, MI, August 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Great Lakes Fish Health Committee Annual Meeting, Grand Rapids, MI, August 2023.

Knupp CK, Lennox SMG, Call D, Soto E, Shavalier MA, Shrestha N, Faisal M, & Loch TP#. Flavobacteria: An Emerging and Resurging Threat to Fish Health Worldwide. Invited Virtual Seminar for the Egyptian Aquatic Health Association Monthly Seminar series, Cairo, Egypt, August 2023.

Shrestha N#, Kebus M, Lennox S, Shavalier M, Knupp C, Pilarski F, Smith M, Phelps N, Loch TP. Investigating the Geno- and Serotypic Diversity of *Flavobacterium psychrophilum* Infecting

Captive-Reared Salmonids of the North Central Region of the USA. Presented at the Michigan Dept. of Natural Resources Fish Production Section Meeting, East Lansing, MI, August 2023.

Loch TP, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Presented at the Michigan Dept. of Natural Resources Fish Production Section Meeting, East Lansing, MI, August 2023.

Phelps NB#, Loch TP, Kebus M, Smith MA. Prioritizing Fish Health Research and Outreach Activities in the North Central Region, USA. Presented at the Annual American Fisheries Society – Fish Health Section, Burlington, VT, July 2023.

Shrestha N#, Kebus M, Lennox S, Shavalier M, Knupp C, Pilarski F, Smith M, Phelps N, Loch T. Investigating the Geno- and Serotypic Diversity of *Flavobacterium psychrophilum* Infecting Captive-Reared Salmonids of the North Central Region of the USA. Presented at the American Fisheries Society – Fish Health Section Virtual Summer Seminar Series, July 2023. Best Student Presentation Award.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Fish farming 101 for veterinarians; What veterinarians need to know about how fish are raised (on farms). Invited Presentation at the Annual Conference of the American Veterinary Medical Association Annual Conference, Denver, CO, July 2023.

Knupp CK, Lennox SMG, Call D, Soto E, Ivan L, Brenden T, Shavalier M, Shrestha N, Loch TP#. Prevention and Control of Bacterial Coldwater Disease: Perspectives from Michigan. Invited Virtual Presentation for USFWS National Hatchery System Guest Webinar, May 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Virtual NOAA Sea Grant, Great Lakes Regional Aquaculture Call, May 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at commercial fish farm, WI, May 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Fish Health Selective Course, University of Wisconsin-Madison, School of Veterinary Medicine, Madison, WI, May 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Aquatic Veterinary Medicine Clerkship, Michigan State University, College of Veterinary Medicine, Virtual Veterinary Nursing Seminar, East Lansing, MI, April 2023.

Loch TP#, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Invited Presentation at the US Trout Farmers Association Session,

Aquaculture America, New Orleans, LA, February 2023.

Loch TP#, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Efforts to Advance Fish Farm Fish Health by the New Aquaculture Outreach Veterinarian in The North Central States. Invited Presentation at American Association of Fish Veterinarians Session, Aquaculture America, New Orleans, LA, February 2023.

Loch TP#, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Invited Presentation at the Wisconsin/Minnesota Aquaculture Conference, Eau Claire, WI, February 2023.

Loch TP#, Kebus M#, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving Fish Health in the NCR by Integrating Outreach with the Development of Alternative Disease Prevention Methods. Invited Presentation at the Michigan Aquaculture Association Meeting, Clare, MI, February 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Virtual Michigan State University, College of Veterinary Medicine, Veterinary Nursing Seminar, East Lansing, MI, February 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Virtual Michigan State University, College of Veterinary Medicine, World Aquatic Veterinary Medicine Student Chapter Seminar, East Lansing, MI, January 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Virtual Michigan State University, College of Veterinary Medicine, Pathology Club Seminar, East Lansing, MI, January 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Ohio Aquaculture Conference, Columbus, OH, January 2023.

Kebus M#, Loch TP, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Invited Presentation at the Virtual University of Florida Aquaculture Graduate Student Seminar, Gainesville, FL, January 2023.

Darling SL, Smith MA, Phelps NB, Vogler D, Emerson M, Summerfelt S, Kebus M, Loch TP#. Improving fish health in the NCR by integrating extension with the development of alternative disease prevention methods. Presented at the Virtual USDA-NIFA NCRAC 2022 Annual Program Meeting, March 2022.

Darling SL#, Smith MA, Phelps NB, Knupp CK, Loch TP. Improving Fish Health In The North Central Region By Developing Alternative Disease Prevention Methods. Presented at the 17th

Annual Michigan State University Department of Fisheries and Wildlife Graduate Student Research Symposium, East Lansing, MI, February 2022.

Manuscripts

Doctolero, Jemuel S, Aya S. Hussain, Thomas To-Hung Tsui, Robert P. Anex, Jen-Yi Huang, and Paul B. Brown. Life cycle assessment of aquaculture farms in the North Central Region of the United States. Journal of Sustainable Production and Consumption.

Zaczek, K., Molinari, G. S., Sohrabifar, A., Holmquist, H., Rode, R., Brown, P., Kwasek, K., Fakhraei, H., Smith, M., & Garvey, J. E. (2025). Split-pond and Pond-side Tank Culture Improves Size Homogeneity of Fingerling Largemouth Bass (*Micropterus nigricans*). **(To be submitted)**

Sohrabifar, A., Zaczek, K., Molinari, G. S., Holmquist, H., Rode, R., Brown, P., Kwasek, K., Fakhraei, H., Smith, M., & Garvey, J. E. (2025). Investigating Nitrogen Cycle and Water Quality in Alternative Pond-Based Production Systems for the Rearing of Largemouth Bass (*Micropterus nigricans*). **(To be submitted)**

Paper: Zhai SW, Lu X, Yang S, Binkowski FP, Deng DF. Optimal Feeding Rates for Growth Performance, Nutrient Retention, and Heat Shock Protein 70 Expression in Fingerling Yellow Perch (*Perca flavescens*). Animals (Basel). 2025 May 19;15(10):1465. doi: 10.3390/ani15101465

Theses and Dissertations

Faruk, O. (2024). A Comprehensive Study on Design, Construction, Cost Analysis, and WaterQuality Assessment in Alternative Pond Production Systems. Southern Illinois University – Carbondale. https://opensiuc.lib.siu.edu/theses/3216.

Sohrabifar, A. (2025). Water Quality Examination of Alternative Pond-Based Production Systems for Rearing Largemouth Bass (*Micropterus nigricans*). Southern Illinois University – Carbondale.

Boessen, P. 2023. Yellow Perch Response to Asian Carp Hydrolysate. Master's thesis, Southern Illinois University, Carbondale, IL. In Progress (anticipated graduation date: December, 2025).

Kebus M, Loch TP, Smith MA, Phelps N. (2025) Fish farmer perspectives on fish health management and veterinary involvement in the North Central Region, USA. *Journal of American Veterinary Medical Association.* https://doi.org/10.2460/javma.25.01.0037

Haake CJE, Hickey N, Kebus MJ, Snekvik K. (2025) Pale skin lesions cranial to the dorsal fin on the dorsum of farmed rainbow trout fingerlings (*Oncorhynchus mykiss*). *Journal of American Veterinary Medical Association* 263(11):1-4. doi: 10.2460/javma.25.06.0371

Shrestha N, Kebus M, Lennox S, Shavalier M, Knupp C, Pilarski F, Smith M, Phelps N, Loch TP. (In preparation) Genotypic, serotypic, and *in vivo* virulence characterization of *Flavobacterium psychrophilum* variants circulating in cultured salmonids (Family *Salmonidae*) the North Central Region of the USA.

Shrestha N, Kebus M, Smith M, Phelps N, Loch TP. (In preparation). *In vivo* experiments provide evidence for protective effects of formalin-killed autogenous *F. psychrophilum* bacterins against bacterial coldwater disease in immersion challenged fingerling rainbow trout (*Oncorhynchus*

mykiss).

Journal Articles and Abstracts

Peer Reviewed

Kaur, M., Dabrowski K., Fisher K., Hossain M.Z., Barringer S. "Effect of Rearing, Physiological, and Processing Conditions on the Volatile Profile of Atlantic Salmon (Salmo salar) using SIFT-MS" Foods. (2025), 14, 2540.

Haake, C.J., Hickey, N., Kebus, M.J. and Snekvik, K., 2025. Pale skin lesions cranial to the dorsal fin on the dorsum of farmed rainbow trout fingerlings (Oncorhynchus mykiss). Journal of the American Veterinary Medical Association, 1(aop), pp.1-4.

Kebus, M., Loch, T.P., Smith, M. and Phelps, N.B., 2025. Opportunities for veterinary engagement to improve aquaculture production and the health of farmed fish in the North Central Region of the United States. Journal of the American Veterinary Medical Association, 1(aop), pp.1-6.

Articles

Nugent, C. Fishing for a Solution: Grace Lansdell studies how to keep birds away from fish farms. Kansas State Agriculturist Magazine. 71(2) 2025.

Extension/Outreach Publications

MU Aquaculture Extension Website Link to NCRAC project publications and presentations is available at, https://extension.missouri.edu/programs/aquaculture-and-fisheries-extension/north-central-regional-aquaculture-project

North Central Region Aquaculture Industry: Trends and Outlook
https://extension.missouri.edu/publications/mx465

Advancing Aquaculture in the Midwestern Region; Farm Site Visits
https://extension.missouri.edu/publications/mx469

Understanding Consumer Preferences for Aquaculture Produces in the Midwest
https://extension.missouri.edu/publications/mx467

US Consumers' Willingness to Pay for Trout, Walleye and Yellow Perch, and Selected Aquaculture Products Attributes https://extension.missouri.edu/publications/mx468

North Central Region Aquaculture Business Models Summary
https://extension.missouri.edu/publications/mx466

Presentation at the Institute of Biological Engineers Annual Conference, September 12–13, 2025, Salt Lake City, Utah, "Advancing Aquaculture in the Midwestern Region,"
https://extension.missouri.edu/media/wysiwyg/Extensiondata/Pro/AquacultureExtension/Docs/advancing-aquaculture-in-the-midwest-region-presentation.pdf

Amy Shambach, Michal Wojno, Karolina Kwasek, Tyler Firkus, Emma Hauser, Stuart Carlton. Fish Muscle Hydrolosate: A Novel Method for Producing Dietary Protein from Invasive Species

for Fish Larvae. 2025. Illinois-Indiana Sea Grant Report IISG24-SFA-BRC-022.
Firkus, Tyler J., Boesen, Peter F., Wojno., M., Kwasek, K., Hauser, Emma M., Neibauer, Jared L., Branville, C. The use of hydrolyzed protein from non-native carp species to improve growth and survival in walleye (*Sander vitreus*) larval aquaculture (*in review*).

Oral Presentations

Kaur, M., Dabrowski K., Fisher K., Barringer S. (2025, March). Effect of rearing temperature, gender, skin off vs skin on muscle, fillet location, freezing and storage on the volatile profile of Atlantic salmon Salmo salar using SIFT-MS. World Aquaculture Society (WAS) Conference, New Orleans, Louisiana, USA.

Dabrowski K., Fisher K., Hossain ZM, Kaur M Barringer S, Coole R, Belury M. (2025, March). Atlantic salmon maturation under impact of temperature and light regimes - preliminary studies in small recirculation system. World Aquaculture Society (WAS) Conference, New Orleans, Louisiana, USA.

Kebus M#. Fish Farm Cases-what you may see and be asked to diagnose and treat. Invited presentation at the Annual Conference of the American Veterinary Medical Association, Washington, D. C. July 19, 2025. (Non-NCRAC Funds)

Kebus M#. Aquaculture Veterinary Medicine - Getting Started. Invited presentation at the Annual Conference of the American Veterinary Medical Association, Washington, D. C. July 19, 2025. (Non-NCRAC Funds)

Kebus M#. Strengthening the Fish Farm Veterinary Workforce, Fish Farm Biosecurity, and Enhancing Aquatic Animal Disease Preparedness and Response in the North Central Region. Invited presentation at the Eastern Fish Health Workshop, Grand Rapids, Michigan, March 20, 2025. (NCRAC Funds)

Kebus M#. Peter Fritsch, WI Fish Health Case Study. Invited presentation at the Wisconsin Aquaculture Association Annual Conference, Marshfield, Wisconsin, February 21, 2025. (NCRAC Funds)

Kebus M#. Strengthening the Aquaculture Veterinary Workforce. Invited presentation at the Veterinary Services Aquaculture Health Session - Showcasing what we do for US Aquaculture, Aquaculture Americas 2025, New Orleans, Louisianna, March 10, 2025. (Non-NCRAC Funds)

Kebus M#. Strengthening the Aquaculture Veterinary Workforce. Invited presentation at the in Innovative Veterinary Practices in Aquaculture Session, at Aquaculture Americas 2025, New Orleans, Louisianna, March 8, 2025. (Non-NCRAC Funds)

Kebus M#. NCRAC Fish Health Initiatives, Dr. Myron Kebus, Aquaculture Outreach Veterinarian, North Central Regional Aquaculture Center (NCRAC). Invited presentation at the, Missouri Aquaculture Conference, Kansas City, Missouri, February 7, 2025. (Non-NCRAC Funds)

Kebus M#. Aquaculture Veterinary Outreach - Myron Kebus, MSU, Michigan Aquaculture. Invited presentation at the Michigan Aquaculture Association Meeting, January 30, 2025. (NCRAC Funds)

Kebus M#. Fish Health Q&A. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025 (NCRAC Funds)

Kebus M#. Recent Disease Cases - Diagnosis, Treatment, and Prevention. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025 (NCRAC Funds)

Kebus M#. NCRAC Fish Health Initiative: Update and 2025 Activities, Dr. Myron Kebus, Aquaculture Outreach Veterinarian, Michigan State University. Invited presentation at the Ohio Aquaculture Association Annual Conference, Columbus, Ohio, January 24, 2025 (NCRAC Funds)

Kebus M#. Getting Started in Fish Farm Veterinary Medicine Part 1, 2. 3. Invited presentation at the Michigan Veterinary Conference, CE Session | Food Animal Track. Grand Rapids, MI. November 2, 2024 (NCRAC Funds)

Kebus M#. Haake, C. Rainbow Trout: Case Steatitis. Invited presentation at the Special Pathology Seminar: Case-Based Presentations from the Field and the Microscope, American Association of Fish Veterinarians 2024 Annual Conference. Seattle, WA, October 21, 2024. (Non-NCRAC Funds)

Kebus M#. Aquaculture Veterinary Medicine. Invited presentation at the American Association of Fish Veterinarians 2024 Annual Conference. Seattle, WA, October 19, 2024.(Non-NCRAC Funds)

Sohrabifar, A., Zaczek, K., Molinari, G. S., Holmquist, H., Rode, R., Brown, P., Kwasek, K., Fakhraei, H., Smith, M., & Garvey, J. E. (2025). Investigating Nitrogen Cycle and Water Quality in Alternative Pond-Based Production Systems for the Rearing of Largemouth Bass (*Micropterus nigricans*). Presented at World Aquaculture Society in New Orleans, LA, USA, March of 2025.

Zaczek, K., Molinari, G. S., Sohrabifar, A., Holmquist, H., Rode, R., Brown, P., Kwasek, K., Fakhraei, H., Smith, M., & Garvey, J. E. (2025). Split-pond and Pond-side Tank Culture Improves Size Homogeneity of Fingerling Largemouth Bass (*Micropterus nigricans*). Presented at World Aquaculture Society in New Orleans, LA, USA, March of 2025.

Zaczek, K., Molinari, G. S., Sohrabifar, A., Holmquist, H., Rode, R., Brown, P., Kwasek, K., Fakhraei, H., Smith, M., & Garvey, J. E. (2025). Split-pond and Pond-side Tank Culture Improves Size Homogeneity of Fingerling Largemouth Bass (*Micropterus nigricans*). Presented at American Fisheries Society in San Antonio, TX, USA, August of 2025.

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Anam Ali. Purdue University, PhD candidate.

Austin Berenda. Purdue University, Graduate student.

Manpreet Kaur. The Ohio State University, PhD candidate.

Md Zakir Hossain. The Ohio State University, PhD candidate.

Kevin Fisher. The Ohio State University, PhD candidate.

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Some Commonly Used Abbreviations and Acronyms

AIS	aquatic invasive species
APHIS	Animal and Plant Health Inspection Service
ARS	Agriculture Research Service
AREF	Aquaculture Regional Extension Facilitator
AquaNIC	Aquaculture Network Information Center
BOD	Board of Directors
BW	body weight
□C	degrees Celsius
CES	Cooperative Extension Service
COD	chemical oxygen demand
CSFPH	Center for Food Security and Public Health
CVM	Center for Veterinary Medicine
FSR	final study report
ft, ft^2, ft^3	foot, square foot, cubic foot
FY	fiscal year
g	gram(s)
gal	gallon(s)
h	hour(s)
ha	hectare(s)
HACCP	Hazard Analysis and Critical Control Point
HCG	human chorionic gonadotropin
IAC	Industry Advisory Council
INAD	investigational new animal drug
ISU	Iowa State University
KAA	Kansas Aquaculture Association
LU	Lincoln University
m, m^2, m^3	meter(s), square meter, cubic meter
MAI	motile *Aeromonas* infection
MAS	motile *Aeromonas* septicemia
MDNRE	Michigan Department of Natural Resources and Environment
µg	microgram(s)
mg	milligram(s)
MC	Mill Creek
min	minute(s)
mL	milliliter(s)
mm	millimeter(s)

MSU	Michigan State University
MT	methyltestosterone
N	number
NAA	National Aquaculture Association
NADA	new animal drug application
NASAC	National Association of State
NCC	National Coordinating Council
NCR	North Central Region
NCRAC	North Central Regional Aquaculture
NIFA	National Institute of Food and Agriculture
NOB	nitrite oxidizing bacterial
OCARD	Ohio Center for Aquaculture Research and Development
OSU	The Ohio State University
oz	ounce(s)
PAH	Phibro Animal Health
PCR	polymerase chain reaction
PFU	plaque-forming units
POW	Plan of Work
ppm, ppt	parts per million, parts per thousand
Purdue	Purdue University
RAC(s)	Regional Aquaculture Center(s)
RAES	Regional Aquaculture Extension
RAET	Regional Aquaculture Extension Team
RAS	recirculating aquaculture system
RS	Rimler-Stotts
SPAH	Schering-Plough Animal Health
TC	Technical Committee (TC/E = Technical
™	trademark
TSA	Tryptic Soy Agar
UMESC	Upper Midwest Environmental Sciences
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
UW-Madison	University of Wisconsin-Madison
UW-Milwaukee	University of Wisconsin-Milwaukee
VHS	viral hemorrhagic septicemia
VHSv	viral hemorrhagic septicemia virus
WATER	Wisconsin Aquatic Technology and Environmental Research

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