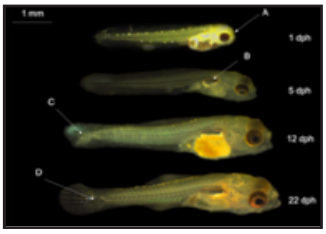
May 2024

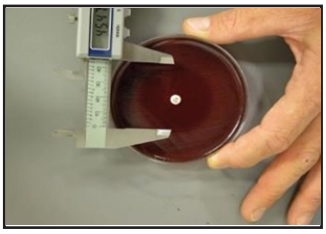
34th ANNUAL PROGRESS REPORT

SRAC

PR VI

Supporting research and Extension projects based on industry needs and designed to directly impact commercial aquaculture development.








For the period through December 31, 2022

USDA NIFA

United States Department of Agriculture
National Institute of Food and Agriculture

THIRTY-FOURTH ANNUAL PROGRESS REPORT

USDA NIFA SOUTHERN REGIONAL AQUACULTURE CENTER
Jimmy Avery, Director
Kristen Thompson, Business Manager
P.O. Box 197
Stoneville, Mississippi 38776
Phone: 662-686-3273
Fax: 662-686-3320
E-mail: srac@drec.msstate.edu
Website: http://www.srac.msstate.edu/

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This Thirty-Fourth Annual Progress Report seeks to provide 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 SRAC during this reporting period are available at http://www.srac.msstate.edu/annualprogressreports.html. In the past year, SRAC funded projects totaling more than $1.93 million. During the past year, these projects have resulted in 14 journal articles, 8 Extension/Outreach publications, 2 workshops, 9 peer-reviewed fact sheets, 41 oral presentations, 2 poster presentations, 5 digital products, and has supported 3 post-doctoral fellows, 7 Ph.D. students, 4 M.S. students, 3 graduate students, and 5 undergraduates

Reduction of Artemia Use and Replacement with Fortified Rotifers or Artificial Feeds

The rearing of larval finfish typically requires the use of live foods. One of the most popular larval foods is *Artemia salina* (hereafter referred to as Artemia), often wild harvested from the Great Salt Lake or other areas. However, there are limits to the wild harvest, so alternatives that can reduce dependency on Artemia could have not only positive ecological but also economic implications. Because Artemia is widely used in the aquaculture industry and serves as an essential first food or transition food, improvements in its use or development of suitable alternatives are needed. This project has pursued a variety of approaches to reduce the dependence on Artemia in the feeding of larval stages of various fish species. The various research approaches are being pursued by several investigators from three institutions.

Economic Impact and Technology Adoption in U.S. Catfish Industry

The catfish industry continues to be a leading and sustained economic segment in the tri-state regional economies of Alabama, Arkansas, and Mississippi. The economic contribution of the catfish industry to the tri-state region totaled $1.9 billion in 2019. The industry contributed over 9,100 jobs to the regional economy and generated more than $78 million in federal and state tax revenue. The state of Mississippi, with farms, processing plants, and feed mills, is the greatest contributor to the regional economy ($1.3 billion) followed by the state of Alabama ($0.5 billion). The catfish industry was found to support more than 97% of the industries listed in the IMPLAN database for the tri-state regional economy. The study also found that the catfish industry is evolving through the increased adoption of more intensive productivity-enhancing technologies such as intensively aerated ponds and split-pond systems. More than 33% of the catfish production area in 2019 was under intensive-system production. The average aeration rate in the industry in 2019 was 4.2 hp/acre. More than 96% of the surveyed farms had adopted automated oxygen monitoring systems. About 53% of the catfish production area was using hybrid catfish. Over two-thirds of the fingerling production area was vaccinated against ESC at the time of the survey.

Epidemiology of *Edwardsiella piscicida*

Genotypic profiling established genetic variability among catfish-derived *E. piscicida* isolates and identified five discrete *E. piscicida* phyletic lineages exhibiting group-specific associations with several virulence genes. Plasmids from the studied *E. piscicida* isolates significantly varied in plasmid content and organization and the unique plasmid sequences have been submitted to GenBank (MZ098222–MZ098227). Phenotypic profiling of representative *E. piscicida* isolates revealed alterations in growth characteristics with respect to incubation temperatures, salt concentrations, and nutrient types. However, there were no phenotypic variations among the studied *E. piscicida* isolates from different

genotypes. Challenge studies using *E. piscicida* representatives from each phylogroup indicated significant mortalities in hybrid catfish compared to channel catfish. Histopathological assessment of the infected fish did not reveal any specific trends with respect to *E. piscicida* genotypes. The cross-protective potential of the *E. ictaluri* vaccine against *E. piscicida* in catfish was confirmed abating the need for an *E. piscicida*-specific vaccine. *Edwardsiella piscicida* susceptibility study in Nile tilapia (*Oreochromis niloticus*) reported significant differences in mortality with respect to bacterial isolates from different genetic clades suggesting an underlying genetic basis for strain virulence and potential host associations. The *E. ictaluri* vaccine did not confer protection in immunized tilapia upon exposure to *E. piscicida* (S11-285). So far there are no results to report from the economic analysis.

Management Strategies for ESC in Ornamental Fish

The results of this work demonstrate that the isolates from ornamental fish are largely a clonal population with negligible genetic variability. Further, native plasmids among ornamental isolates were also consistent and harbored no recognized antibiotic resistance genes. This would indicate management practices (vaccines; probiotics; antimicrobial regimes) should be consistent across multiple isolates from different facilities and geographic regions. Live attenuated mutant strains which were not harmful to zebrafish in preliminary challenges could be developed successfully. Enrofloxacin and florfenicol drug studies using a closely related species, the giant danio, will help producers more accurately dose medicated feeds for effective disease treatment. Probiotics added to pond water will shift the intestinal bacterial communities of zebrafish, can enhance numbers of “good bacteria” and may help reduce losses from *E. ictaluri*.

Improving the Position of Southern Aquaculture Products in the Grocery Marketplace

The U.S. seafood markets are highly competitive and diversified in terms of species sold and product forms. Domestic aquaculture producers have to be highly competitive to survive in this global marketplace dominated by imports. Domestic producers who are at the lower end of the supply chain are often unaware of the dynamic consumer interactions that occur in retail markets. Success in these dynamic and competitive environments can only be achieved by making effective marketing decisions. Such decisions rely on the availability of information about actual consumer behavior in retail markets as proper analysis of such downstream signals could help formulate effective marketing strategies. This is vital for improved positioning of Southern aquaculture products. Seafood retail scanner data is one of the best sources of information that cover the magnitude, dynamism, and diversity of the U.S. seafood grocery markets. These big data are generated by scanning the Universal Product Code or the barcode of the products. This project is aimed at tailoring marketing information relevant to the southern aquaculture industry by focusing on seafood sales in grocery stores and purchases of seafood at the household level in major markets. To examine retail market trends for seafood in the U.S., seafood scanner data (ScanTrack®) were purchased from A.C. Nielsen Consumer LLC.

Evaluation of Probiotics and Prebiotics in Finfish Hatcheries

This project has focused on the evaluation of two commercially available probiotics (Aquaculture Blend from Bio-Cat and Bactocell from Lallemand) and two commercially available prebiotics (GroBiotic®-A from International Ingredient Corporation and SiLO Health® from BASF, Germany). These supplements have been evaluated by administering individually during hatchery production trials of domesticated striped bass, red drum, and Southern flounder. Several different lines of investigation have been pursued in this project and have provided assorted results, some which related directly to prebiotic and probiotic administration, and others to different aspects of larval fish rearing. The administration of prebiotics and probiotics to rotifers was developed such that changes in the microbial composition of

the foods was achieved. Significant improvements in swimbladder inflation of domesticated striped bass was necessary to accomplish the feeding trials and has been partially achieved through a combination of techniques. In addition, advances in automated feeding systems for administering Artemia have been made and will enhance the precision by which feeding occurs.

Publications, Videos, and Computer Software

The Southern Regional Aquaculture Center commenced the Publications, Videos, and Computer Software Project in order to provide these materials in a timely and relevant manner. Since that time, 358 technical fact sheets (248 in the current catalog), 102 update revisions, 7 web presentations, 7 software programs or web tools, and 31 videos have been produced. In the current reporting year alone, 36,678 unique users from 140 countries and territories used the SRAC Publications website, https://srac.tamu.edu/, to view or download SRAC publications 98,620 times. SRAC videos were viewed on the SRAC YouTube channel 18,763 times during the current reporting period. The AquaPant website, created with funding from the SRAC PVCS Project, had 196,909 unique users that viewed 527,612 webpages during the reporting period. These users were from 200 countries/territories. These analytics demonstrate that the SRAC Publications, Videos, and Computer Software project truly has worldwide reach and impact.

Rapid Detection Methods for Emerging Aquatic Animal Pathogens

There is an urgent industry defined need for rapid, sensitive methods to detect emerging aquatic animal pathogens in their hosts and environments. Real-time, quantitative PCR (qPCR) primers and probes have been developed and validated, thus providing rapid, highly sensitive methods for detecting pathogens in the environment and host tissues. These assays will advance aquaculture production in the short and long term by providing means to confirm fish/oysters imported or raised by farmers are free of these pathogens, while improving biosecurity. Additionally, these assays, once fully validated, can be implemented in state and national surveillance efforts

Novel Flavobacterium Columnare Vaccine Candidates

In the southeastern United States, columnaris disease is responsible for significant losses in the catfish industry, along with other economically important fish species. The development of an efficacious vaccine to prevent and control columnaris disease has been restricted partially due to a lack of understanding of the broad genetic diversity of columnaris-causing bacteria. Outputs generated during this reporting period include the development of eighteen rifampicin-resistant strains of columnaris-causing bacteria. Additionally, five of these strains have been confirmed to be attenuated through in vivo virulence assessment.

Emergence of Vibriosis in Catfish Hatcheries

Over the past several years, Vibriosis caused by *Vibrio* spp. has been identified as a cause of isolated losses in catfish hatcheries located in the Mississippi Delta. Isolates recovered from spontaneous mortality events have been identified as *V. cholera* by multiple genetic and phenotypic methods, including multi-locus sequence typing and genomics. These isolates have been identified as non-toxigenic or non-cholera V. cholerae, as all isolates from catfish hatcheries have been negative for the cholera toxin (CTX) gene. In response to repeated annual outbreaks of Vibriosis in catfish hatcheries, producers have reduced the biomass they are carrying in hatcheries as well as made more concerted efforts to avoid holding fish for extended periods. These efforts appear to have reduced incidence of Vibriosis in catfish hatcheries in the Mississippi Delta.

INTRODUCTION

Mission

The mission of the USDA NIFA Southern Regional Aquaculture Center (SRAC) is to support aquaculture research, development, demonstration, and education to enhance viable and profitable U.S. aquaculture production to benefit consumers, producers, service industries, and the American economy. Projects that are developed and funded are based on industry needs and are designed to directly impact commercial aquaculture development in the southern region and the nation.

Background

The Agriculture Acts of 1980 and 1985 authorized establishment of aquaculture research, development, and demonstration centers in the United States. With appropriations provided by Congress for the 1987 and 1988 FYs, efforts were undertaken to develop the five Regional Aquaculture Centers now in existence. Organizational activities for SRAC began in 1987, with the first research and Extension projects initiated in 1988.

In 1980, Congress recognized the opportunity for making significant progress in domestic aquaculture development by passing the National Aquaculture Act (P.L. 96-362). The Act established USDA as the lead agency for aquaculture coordination and called for development of a National Aquaculture Plan. The next year, Congress amended the National Agricultural Research, Extension, and Teaching Policy Act of 1977 (P.L. 95113) by granting, in Title XIV, Subtitle L, Sec. 1475(d) of the Agriculture and Food Act of 1981 (P.L. 97-98), authority to establish aquaculture research, development, and demonstration centers in the United States. Funding for the Centers was reauthorized in subsequent Farm Bills (the Food, Agriculture, Conservation, and Trade Act of 1990 [P.L. 101- 624]; the Agriculture Improvement and Reform Act of 1996 [P.L. 104-127]; the Farm Security and Rural Investment Act of 2002 [P.L. 107-171]; and the Food, Conservation, and Energy Act of 2008 [P.L. 110-246]). The Agricultural Act of 2014 [P.L. 113-179] stipulated that these were “Competitive” grants and changed the authorized appropriations from $7.5 million to $5 million for each of fiscal years 2014 through 2018.

Congress envisioned the Centers as focal points in a national program of cooperative research, Extension, and development activities that would be developed in association with colleges and universities, state Departments of Agriculture, federal facilities, and non-profit private research institutions with demonstrated excellence in aquaculture research and Extension. Eventually, five such Centers were established: one in each of the Northeastern, North Central, Southern, Western, and Tropical Pacific regions of the country.

Although government agencies, particularly the USDA, have provided significant support for aquaculture research and development, much of that funding is earmarked for specific use by specific institutions. The USDA NIFA Regional Aquaculture Center program is the only funding activity with the flexibility to stay abreast of industry development, identify problems on a region-wide scale, and implement cooperative, interstate projects to solve those problems.

Since its inception in 1987, SRAC has become the most important regional aquaculture activity in the southeastern United States. In its 37 years of operation, the Center has disbursed more than $20.2

million to fund multi-state research and Extension projects. More than 200 scientists from 41 institutions in the southeast have participated in Center projects.

Productivity from SRAC research projects has been excellent since the Center's inception more than three decades ago. Information derived from SRAC-funded projects has been transferred to producers and other scientists in thousands of scientific papers and presentations. Currently funded projects continue this trend of high productivity.

Beginning with the first projects funded by SRAC, interest among aquaculture research and Extension scientists in Center activities has been excellent. In fact, funding and project coordination provided by SRAC has become so embedded in the fabric of southeastern aquaculture research and Extension that it is difficult to envision what these activities would be like without the program. We are pleased with the participation by our research and Extension scientists in the Southern Region in *ad hoc* Work Group meetings and Steering Committees, and their willingness to serve as Project Leaders and Principal Investigators for the projects. We believe this broad-based representation has resulted in strong, cooperative research that will be of long-lasting benefit to aquaculture producers and consumers, and to the growth of the aquaculture industry in the Southern United States.

Acknowledgments

The Southern Regional Aquaculture Center acknowledges the contributions of the Project Leaders and Participating Scientists involved in the projects reported in this Thirty-Fourth Annual Progress Report. Members of the SRAC Board of Directors, Industry Advisory Council, and Technical Committee have provided valuable inputs to the successful operation of SRAC during the past year. We particularly appreciate the assistance of the Chairs of these vital committees.

We also thank the scientists and aquaculturists from across the country who contributed their expertise and valuable time to review SRAC project proposals and publications. Without their help, it would be impossible to maintain the high quality of this program.

ORGANIZATIONAL STRUCTURE

Research and Extension problem areas for the southern region are identified each year by the Industry Advisory Council (IAC), which consists of fish farmers and allied industry representatives from across the region. The Technical Committee (TC), consisting of research and Extension scientists from states within the region, works with the IAC to prioritize problem areas. The two groups then work together to develop "Requests for Pre-proposals" describing objectives of work to solve problems with the highest priority. The best proposals submitted by individuals or teams are used to form a regional Work Group that plans and conducts the work. Regional aquaculture funds are allocated to participants in SRAC projects approved by the Board and NIFA. Reviews of project proposals, progress reports, and recommendations for continuation, revision, or termination of projects are made jointly by the TC and IAC and approved by the Board.

The thirteen states and two territories represented by SRAC are Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, U.S. Virgin Islands, and Virginia.

Administrative Center

The Administrative Center is located at the Delta Research and Extension Center, Stoneville, Mississippi. Mississippi State University serves as the Host Institution. All necessary support services for the Board, IAC, TC, Steering Committees, and project Work Groups are provided by the Administrative Center. This includes monitoring status and progress of projects, preparing and executing Letters of Agreement, tracking administrative and project expenditures, reviewing progress reports, and assisting Project Leaders and participating institutional Grants Offices as needed.

Operation and funding are approved by the Board for inclusion in the Grant Application submitted annually to USDA NIFA. The Center staff also prepares and submits to USDA NIFA an Annual Plan of Work covering Center activities and projects to be funded. Following final approval, Letters of Agreement are prepared and executed with all participating institutions. The Center acts as fiscal agent to disburse and track all funds in accordance with the provisions of the grants.

Board of Directors

The Board is the policy-making body for SRAC. Membership provides an appropriate balance among representatives from State Agricultural Experiment Stations, Extension Services, 1890 Institutions, and the Administrative Heads Section of the Board on Agriculture Assembly of the Association of Public and Land Grant Universities.

The Board is responsible for 1) overall administration and management of the regional center program; 2) establishment of overall regional aquaculture research and Extension goals and allocations of fiscal resources to ensure that the center develops strong programs in both research and Extension; 3) approval of priorities for regional aquaculture research and Extension education activities based on inputs from the TC and IAC; 4) review and approval of annual plans of work and accomplishment reports; and 5) final selection of proposals for funding by SRAC.

Members of the Board for the reporting period were:

Keith Coble, Mississippi State University (Chair)
Phil Elzer, Louisiana State University AgCenter
Bob Scott, Univ. of Arkansas
Steve Lommel, North Carolina State University
Ashley Stokes, University of Tennessee
Scott Willard, Mississippi State University
Steve Martin, Mississippi State University
Edmund Buckner, Alcorn University

Industry Advisory Council

The IAC is composed of representatives of state and regional aquaculture associations, federal, territorial and state agencies, aquaculture producers, aquaculture marketing and processing firms, financial institutions, and other interests or organizations. 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 SRAC.

The IAC 1) identifies research and Extension needs; 2) works with the TC to prioritize research and Extension needs; 3) works with the TC to develop problem statements and recommend funding levels for projects addressing priority research and Extension needs; 4) reviews project proposals and progress reports; and 5) recommends to the Board, jointly with the TC, actions regarding new and continuing proposals, proposal modifications, and terminations.

Members of the IAC for the reporting period were:

Margie Saul, AR
Rick Murdock, KY
Jon Cooper, MS
Martha Campbell, FL
Marty Tanner, FL
David Heikes, AR
Richard Eager, SC
Mitt Walker, AL
Shance Nicaud, LA
Wec Terry, VA
Kim Edge, GA
Douglas Kuenz, LA
Rob Ellis, NC
Frank Roberts, SC
Townsend Kyser, AL
Mark Kubecka, TX
Robert Wright, MS

Technical Committee

The TC consists of representatives from participating research institutions and state Extension services, other state or territorial public agencies as appropriate, and private institutions. Membership of the TC includes research and Extension scientists representing essentially all states in the region. The TC 1) works with the IAC to prioritize research and Extension needs; 2) works with the IAC to develop problem statements and recommend funding levels for projects addressing priority research and Extension needs; 3) reviews proposals and progress reports; and 4) recommends to the Board, jointly with the IAC, actions regarding new and continuing proposals, proposal modifications and terminations.

Members of the TC for research for the reporting period were:

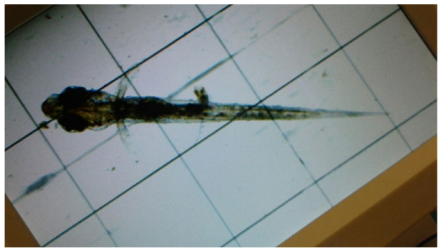
Brian Bosworth, USDA-ARS Warmwater Aquaculture Research Unit
Ben Reading, North Carolina State University
Waldemar Rossi, Jr., Kentucky State University
Allen Davis, Auburn University
Amit Sinha, University of Arkansas at Pine Bluff
Amrit Bart, University of Georgia
Delbert Gatlin, Texas A&M University
Cortney Ohs, University of Florida
Bill Walton, Virginia Tech University
Mike Denson, National Oceanographic and Atmospheric Administration
Brian Callam, Louisiana State University

Members of the TC for Extension for the reporting period were:

Lance Beecher, Clemson University
Mike Frinsko, North Carolina State University
Thomas Bliss, University of Georgia
Luke Roy, Auburn University
Todd Sink, Texas A&M University
Greg Lutz, Louisiana State University
Michael Schwarz, Virginia Tech University
Craig Watson, University of Florida
Forrest Wynne, Kentucky State University
Ganesh Kumar, Mississippi State University
Marley Beem, Oklahoma State University
Creig Kimbro, University of Tennessee
Don Bailey, Univ. of Virgin Islands
Nicholas Romano, Univ. of Arkansas of Pine Bluff

PROGRESS REPORTS

Managing Larval Feeding for Improved Survival by Reduction of Artemia Use and Replacement with Fortified Rotifers or Artificial Feeds



Reporting Period: Sept. 1, 2020 – Dec. 31, 2022
Length of Project: 3 Years
Current Project Year: 3
Total Funds Committed: $283,436
Principal Investigators: Delbert Gatlin, Todd Sink, *Texas A&M University*; Mike Frinsko, Steven Hall, Michael Joseph, Kimberly Livingston, Ben Reading, *North Carolina State University*; Jason Broach, *Waddell Mariculture Center SCDNR*; Michael Denson, Aaron Watson, Erin Levesque, *Marine Resources Division SCDNR*

Relevance: The rearing of larval finfish typically requires the use of live foods. One of the most popular larval foods is *Artemia salina* (hereafter referred to as Artemia), often wild harvested from the Great Salt Lake or other areas. However, there are limits to the wild harvest, so alternatives that can reduce dependency on Artemia could have not only positive ecological but also economic implications. Because Artemia is widely used in the aquaculture industry and serves as an essential first food or transition food, improvements in its use or development of suitable alternatives are needed.

Response: This project has pursued a variety of approaches to reduce the dependence on Artemia in the feeding of larval stages of various fish species. The various research approaches are being pursued by several investigators from three institutions.

Results: Three distinct objectives are being pursued in this project:

1) Define effective feeding mechanisms and strategies to reduce Artemia use in the hatchery.
   Automation of Artemia Feeding. Significant improvements have been made to the automated North Caroline State University (NCSU) *Artemia* feeding system initially developed in a prior project. This has resulted in the creation of a state-of-the-art tablet-mounted GUI control system which has provided the ability to adjust: 1) feeding rate (based on concentration), 2) time of feeding, 3) feeding interval, and 4) concentration, for each treatment associated with *Artemia* feeding experiments.
   Alternative live foods production. Another component of the project has evaluated a refined, simple technology of live foods production for hatcheries that eliminates the high costs and rigorous equipment and labor requirements of intensive larval culture, as well as removes the water waste, uncertain timing of fertilization, and high fish mortality due to predators and temperature fluctuations of extensive larval culture.
2) Evaluate commercially available artificial diets and alternative live food organisms for fresh and saltwater species that are effective replacements to Artemia.
   The project encompassed evaluations of commercially available and experimental artificial diets and alternative live food organisms for freshwater and saltwater fish with larval zebrafish and red drum, respectively, at Texas A&M University (TAMU). Additional trials were conducted with southern flounder (TAMU) and domesticated striped bass larvae (NCSU). Zebrafish were much easier to rear

to juveniles using artificial diets alone compared to red drum, southern flounder and domesticated striped bass.

Feeding trials with three marine baitfish, namely spot, pinfish, and pigfish at the South Carolina Department of Natural Resources, Marine Resources Division, revealed that reductions in survival and growth could be expected with reductions in Artemia feeding when replaced with a dry mixture of larval diets. However, it was encouraging that 66% reduction in Artemia levels for spot along with feeding a dry diet mix yielded similar growth and survival as the 100% Artemia treatment, suggesting spot as a promising candidate for continued research aimed at additional protocols to test the reduction of Artemia levels during their larval phase.

3) Evaluate enrichments of rotifers and other live food organisms to increase their nutritional composition as suitable Artemia replacements.

The research under this objective included the development of regimes in which rotifers could be effectively enhanced with either taurine and/or vitamin C. Replicated assays were conducted at TAMU to refine the level and duration of exposing rotifers to these supplements while maximizing resulting concentrations. Based on the results of several supplementation trials, the concentrations of taurine and vitamin C in rotifers could be readily augmented by simply adding crystalline forms of these nutrients to the rotifer culture medium for as short as 1 h prior to harvest. Given that these two nutrients are generally considered to be limiting in live foods, this means of enhancing their nutrient composition may be routinely applied without undue complications in the live food production process.

The NCSU component of this objective included the following:

Incorporation of INVE "Sep-Art" Artemia to greatly enhance the purity of Artemia hatches compared to traditional methods involving decapsulation. This process uses the same GSL cysts that were used before; however, the Sep-Art cysts were coated with a ferrous material that allows magnetic removal following hatching.

Outreach Overview: It is anticipated that the various activities associated with this project will be of interest to anyone culturing larval fish species or producing live foods or larval feeds. As such, results of the project will be distributed to aquaculturists and other groups through refereed journal publications, articles in trade journals, conferences, and a Southern Regional Aquaculture Center fact sheet. Results from the marine baitfish trials have thus far have been conveyed to visitors of the Waddell Mariculture Center including approximately four scientists, one baitfish producer, and several (100+) members of the general public. At least three outreach presentations to the general public have occurred thus far. Partial results from the experiments were presented in 2022 at the World Aquaculture Society (WAS) meeting in San Diego, and a presentation at the 2023 WAS meeting in New Orleans was given. A presentation concerning nutritional augmentation of rotifers also was given at the 2023 WAS meeting.

Targeted Audiences: This includes aquaculturists working at state or federal fish hatcheries, as well as commercial facilities in which culture of fish species through larval stages is conducted. Results of the marine baitfish experiments have been conveyed to members of the general public in South Carolina to show the importance of sustainable aquaculture practices and the associated research. Results also have been shared with a marine baitfish producer in Florida who has interests in adapting sustainable larval culture protocols for the species tested.

Outputs: To date the primary outputs have been limited outreach events and 2 conference presentations. Additional outputs are anticipated as research activities associated with various parts of the project are finalized.

Outcomes/Impacts: To date, the outcomes and impacts achieved on this project have been internal in that project participants were able to adjust and refine experimental protocols based on initial efforts to address the various objectives of this project. It is anticipated that as more results are generated from this project, major impacts on how larval fish are cultured with live foods and/or larval diets will be realized.

As a result of this study, Texas Parks and Wildlife Department has developed a mobile trailer mounted live-foods harvesting system based upon the Texas A&M design and implemented it into hatchery production for red rum and southern flounder at the Texas Sea Center marine hatchery.

Partnerships Developed:

Texas A&M University

Texas Parks and Wildlife Department
Type: Government
Level: State
Provided larval red drum and southern flounder.

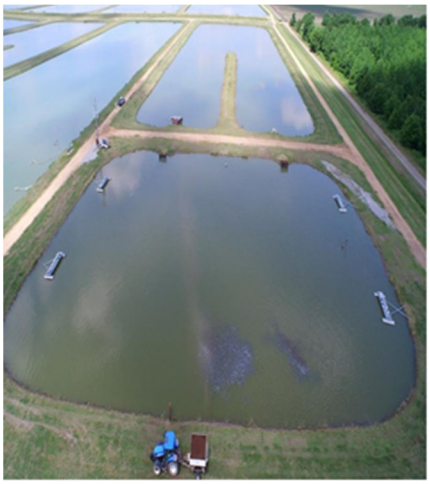
North Carolina State University

Pamlico Aquaculture Field Laboratory
Type: Government
Level: University
Provided larval domesticated striped bass

Waddell Mariculture Center

Nicole Kirchoff of Live Advantage Bait
Type: Industry
Level: Local
Sharing research results as they are obtained

Economic Impact Assessment and Monitoring Progress of Technology Adoption in the U.S. Catfish Industry



Reporting Period: Jan. 1, 2021 – June 30, 2021
Length of Project: 2 Years
Current Project Year: Completed
Total Funds Committed: $111,895
Principal Investigators: Ganesh Kumar, *Mississippi State University*; Carol Engle and Jonathan van Senten, *Virginia Polytechnic Institute and State University*; Terry Hanson and Luke Roy, *Auburn University*; Carol Engle, *Engle Stone Aquatic$, LLC.*

Relevance: The catfish industry has undergone a rapid transformation through adoption of productivity-enhancing technologies to improve profitability. Such dynamic structural changes have many implications for management and for policymakers. This study will produce the most comprehensive, accurate, and current estimates of the economic contribution of the catfish industry along with the progress of on-farm adoption of productivity-enhancing technologies. Accurate estimates of the economic contribution of the catfish industry and technology progress will provide valuable insights for policymakers in making sound policy decisions.

Response: Researchers from three institutions collaborated to quantify the economic contribution of the catfish industry in the three major catfish-producing states of Alabama, Arkansas, and Mississippi. A comprehensive survey of catfish farms and associated backward- and forward-linked supply-chain elements (i.e., feed mills, processors) was designed and launched to collect detailed firm-level data to estimate the economic impact of the catfish industry. The survey was conducted from 2019 to 2020 and collected responses from 68 farms and 14 supply-chain partners of the catfish industry. An analysis-by-part approach using IMPLAN input-output modeling techniques was employed to detail the contribution of the catfish industry to the three state and tristate regional economies, as well as the specific contribution of farms and supply-chain actors to the regional economy for the year 2019. The survey also collected information on ongoing technological progress on catfish farms by measuring the on-farm adoption of alternative catfish production technologies (split-pond, intensively aerated pond, and in-pond raceway systems), complementary technologies (fixed paddlewheel aeration, hybrid catfish, and oxygen monitoring systems) and the extent of adoption of vaccination technology on fingerling operations.

Results: The catfish industry continues to be a leading and sustained economic segment in the tri-state regional economies of Alabama, Arkansas, and Mississippi. The economic contribution of the catfish industry to the tri-state region totaled $1.9 billion in 2019. The industry contributed over 9,100 jobs to the regional economy and generated more than $78 million in federal and state tax revenue. The state of Mississippi, with farms, processing plants, and feed mills, is the greatest contributor to the regional economy ($1.3 billion) followed by the state of Alabama ($0.5 billion). The catfish industry was found to support more than 97% of the industries listed in the IMPLAN database for the tri-state regional economy.

The study also found that the catfish industry is evolving through the increased adoption of more intensive productivity-enhancing technologies such as intensively aerated ponds and split-pond systems. More than 33% of the catfish production area in 2019 was under intensive-system production. The average aeration rate in the industry in 2019 was 4.2 hp/acre. More than 96% of the surveyed farms had adopted automated oxygen monitoring systems. About 53% of the catfish production area was using hybrid catfish. Over two-thirds of the fingerling production area was vaccinated against ESC at the time of the survey.

Outreach Overview: Results of the study will be presented at the Aquaculture America and World Aquaculture Society meetings in 2021 and 2022 as well as at various catfish producer meetings scheduled in Stoneville, MS; Macon, MS; Greensboro, AL; and Hot Springs, AR and CFA meeting in New Orleans. The results were also disseminated to important Extension specialists working with catfish farmers in the tristate region as well as to National and State aquaculture associations.

Targeted Audiences: Targeted audiences included primarily catfish farmers, policymakers, researchers, industry organizations, congressional members and staff, and the general public.

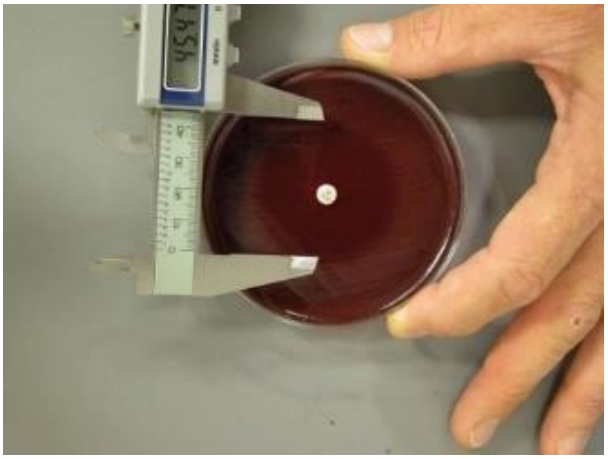
Outputs: Two peer-reviewed manuscripts, two popular articles, 15 presentations, as well as two infographics were produced from this project.

Outcomes/Impacts: This study was instrumental in estimating the extent and intensity of adoption of key production enhancing technologies in the catfish industry. The study also estimated the economic impact of the U.S. catfish industry, the first-of-its-kind effort in U.S. aquaculture. This work captures the most recent trends and dynamics of sales, cost structures, and farming methods in the catfish industry, providing the most comprehensive and current estimates of the economic contribution of the industry and progress of on-farm adoption of productivity-enhancing technologies. Findings are of value for policymakers, Extension specialists, and researchers working with the U.S. catfish industry and U.S. aquaculture in general. This data-intensive approach involving detailed surveys of farms, processing plants, and feed mills to measure the economic contribution of the catfish industry and will pave the way for future regional and national level input-output modeling efforts with domestic aquaculture industries.

Partnerships Developed: Larry Dorman, University of Arkansas at Pine Bluff, Extension Aquaculture Specialist, and Sunni Dahl, Auburn University, Research Assistant III

Investigating the Epidemiology of *Edwardsiella piscicida* -Septicemia in Hybrid Catfish and Other Commercially Important Fish Species in the Southern United States

Reporting Period: Oct. 1, 2019 - Dec. 31, 2022
Length of Project: 3 Years
Current Project Year: Competed
Total Funds Committed: $293,007
Principal Investigators: Suja Aarattuthodiyil, Matt Griffin, Ganesh Kumar, Terry Greenway, Lester Khoo, and David Wise, *Mississippi State University*; Alvin Camus, *University of Georgia*; Carole Engle and Jonathan van Senten, *Virginia Polytechnic Institute and State University*; Larry Dorman and Grace Ramena, *University of Arkansas Pine Bluff*; John Hawke, Louisiana State University; and Esteban Soto, *University of California-Davis*.



Relevance: *Edwardsiella piscicida* is a deadly bacterium with a wide host range affecting >25 economically important fish species. It is highly pathogenic to hybrid catfish and since food-size fish are infected the most, the resulting economic losses can be substantial. There is an industry-defined need to understand similarities and differences among the *E. piscicida* strains affecting the catfish industry and other aquaculture industries. A comprehensive phenotypic and genotypic characterization will be beneficial during disease diagnosis and to develop efficient management strategies against these bacteria. Studies on the stress-induced pathogenesis of *E. piscicida* will provide insights on the disease progression mechanisms and management efforts can be designated in the right direction to mitigate the effects of this deadly disease. Evaluation of the cross-protective potential of the existing *Edwardsiella ictaluri* vaccine against *E. piscicida*- septicemia in catfish and other relevant fish species will infer whether this vaccine can be effectively utilized against *E. piscicida*-septicemia. Estimation of the costs of managing *E. piscicida*-septicemia is especially vital and pertinent given the extent of hybrid catfish adoption in the catfish industry and the increased intensification of catfish aquaculture practices. Identifying such costs is essential for developing pragmatic management tools such as vaccination. Comprehending the pathobiology and pathogenesis of *E. piscicida* is critical to develop effective pathogen-specific control strategies such as vaccines and to provide efficient tools to combat this pathogen.

Response: Disease surveillance of *E. piscicida* in the Southeastern U.S. Case records from the disease diagnostic laboratories (Stoneville, MS; Baton Rouge, LA, and Lake Village, AR) were collected to determine trends associated with *E. piscicida*-septicemia in catfish and other fish species. Pond water samples from hybrid catfish farms were collected twice monthly from April - October and processed for *E. piscicida* detection. Data collection on foodfish production losses due to *E. piscicida* primarily on hybrid catfish ponds will be collected in the third year of this project.

Results: Case records from the disease diagnostic laboratories (Stoneville, MS; Starkville, MS; Baton Rouge, LA, and Lake Village, AR) were collected to determine the annual and seasonal trends associated

with *E. piscicida*-septicemia in catfish and other fish species. Challenge studies indicated *E. piscicida* to be more virulent in hybrid catfish than in channel catfish. Largemouth bass and Nile tilapia were susceptible to catfish-originated *E. piscicida*. Presence of stressors such as high unionized ammonia and physical injury was found to augment *E. piscicida*-infection in fish exposed via immersion mimicking natural infection.
Genotypic profiling established genetic variability among catfish-derived *E. piscicida* isolates and identified five discrete *E. piscicida* phyletic lineages exhibiting group-specific associations with several virulence genes. Plasmids from the studied *E. piscicida* isolates significantly varied in plasmid content and organization and the unique plasmid sequences have been submitted to GenBank (MZ098222–MZ098227). Phenotypic profiling of representative *E. piscicida* isolates revealed alterations in growth characteristics with respect to incubation temperatures, salt concentrations, and nutrient types. However, there were no phenotypic variations among the studied *E. piscicida* isolates from different genotypes indicating that the genetic differences have not transpired into the phenomes of the isolates. Challenge studies using *E. piscicida* representatives from each phylogroup indicated significant mortalities in hybrid catfish compared to channel catfish. Histopathological assessment of the infected fish did not reveal any specific trends with respect to *E. piscicida* genotypes. The cross-protective potential of the *E. ictaluri* vaccine against *E. piscicida* in catfish was confirmed. *Edwardsiella piscicida* susceptibility study in Nile tilapia (*Oreochromis niloticus*) reported significant differences in mortality with respect to bacterial isolates from different genetic clades suggesting an underlying genetic basis for strain virulence and potential host associations. The *E. ictaluri* vaccine did not confer protection in immunized tilapia upon exposure to *E. piscicida* (S11-285).
Commercial production records from fingerling operations impacted by ESC and foodfish (primarily hybrid catfish) losses due to *E. piscicida* were collected. The farm level direct economic loss of Edwardsiellosis ranged between -$1,400 to -$5,300/acre. The direct industrywide economic losses from Edwardsiellosis ranged from -$5.2 to -$17.6 million/year. The lost revenue due to Edwardsiellosis ranged from -$8.4 to -$24.8 million/year. The true economy-wide impact of Edwardsiellosis in the U.S. catfish industry ranged from -$15.5 to -$45.9 million per year. The economic losses and negative impacts of Edwardsiellosis are relatively greater on the foodfish sector. in the third year of this project. So far there are no results to report from the economic analysis.

Outreach Overview: Research findings were presented at the Eastern Fish Health Workshop and World Aquaculture Society meetings in 2020, 2021, and 2022 as well as at the catfish producer meetings at Stoneville, MS.

Targeted Audiences: Fish producers, fish health professionals, extension agents, and researchers.

Outputs: Two peer-reviewed journal articles, one thesis, and several conference abstracts were produced from this project.

Outcomes/Impacts: The project captured the overall trends and prevalence of Edwardsiellosis (caused by *E. piscicida* and *E. ictaluri*) in the catfish industry by compiling 11 years of disease case reports from the major fish disease diagnostic centers. The trends in largemouth bass and barramundi (*Lates calcarifer*) were also recorded.
The virulence of several *E. piscicida* isolates was studied in commercially important fish species such as catfish, largemouth bass, and tilapia. Hybrid catfish was found to be significantly susceptible to *E. piscicida* compared to channel catfish pointing to the need for effective management approaches. Some of the *E. piscicida* isolates caused ~90% mortality in experimentally infected tilapia indicating the

susceptibility of this aquacultured species. Presence of stressors such as high unionized ammonia and physical injury was found to augment *E. piscicida*-infection in fish exposed via immersion mimicking natural infection and thereby offering a reproducible laboratory challenge method. Studies on the stress-induced pathogenesis of *E. piscicida* will provide insights on the disease progression mechanisms and management efforts can be designated in the right direction to mitigate the effects of this deadly disease. Genomic profiling confirmed the presence of genetically diverse *E. piscicida* isolates from the infected fish species. However, these genetic differences do not seem to have transpired into the phenomes of the studied isolates. The ability of *E. piscicida* isolates to grow at different temperatures, nutrient media, and salt levels confirms its ability to adapt to different environmental conditions and habitats.

The cross-protective immunity imparted by the live-attenuated *E. ictaluri* vaccine against *E. piscicida* isolates implicates the multivalent nature of the vaccine and its potential utility in commercial operations. While further efforts for an *E. piscicida*-specific vaccine might be pragmatic, the cross-protection provided by the *E. ictaluri* vaccine could improve production efficiency by curbing disease-associated losses.

The economic approaches used in this study resulted in the first true range estimates of the economic losses with any catfish disease. Septicemia induced by *E. ictaluri* and *E. piscicida* continues to be the second most dominant reported disease in the U.S. catfish industry. The work also quantified the true direct economic effect of Edwardsiellosis at the farm level from comparing production records from commercial catfish that were impacted by Edwardsiellosis.

Estimating the impact of *E. piscicida* septicemia (-$5.8 to -$29.2 million/year) is vital and pertinent given the extent of adoption of hybrid catfish in the catfish industry (53% of the area) and the increased intensification of catfish aquaculture practices. This work sheds light on the economic losses associated with E. ictaluri and *E. piscicida* in catfish aquaculture, providing critical information on the need for the management of economically important diseases such as Edwardsiellosis.

Partnerships: Mark Lawrence, Larry Hanson, Mark Peterman, Lianqun Sun - Mississippi State University; Shraddha Hegde - Texas A&M University; and Luke Roy- Auburn University.

Increasing Understanding of and Developing Management Strategies for *Edwardsiella ictaluri* in Ornamental Fish

Reporting Period: Jan. 1, 2021 – May 31, 2021
Length of Project: 2 Years
Current Project Year: Completed
Total Funds Committed: $204,208
Principal Investigator: Matt Griffin, David Wise, Suja Aarattuthodiyil, *Mississippi State University*; Roy Yanong, Chris Martyniuk, *University of Florida*; John Hawke, *Louisiana State University*

Relevance: Variants of the catfish disease-causing bacteria *Edwardsiella ictaluri* have been reported in the tilapia and ornamental fish industries. Researchers will determine biological differences and similarities between the catfish and ornamental fish strains and evaluate effectiveness of vaccines, antibiotics, natural gut antibacterials, and probiotics to manage the disease.

Response: Archived *E. ictaluri* isolates were obtained from the collections of the MSU-TCNWAC in Stoneville, MS, the LSU-LADL in Baton Rouge, LA, and UF-TAL in Ruskin, FL. Presumptive identification of the isolates was conducted by colony morphology and growth characteristics, which was confirmed using *Edwardsiella ictaluri*-specific PCR. A rifampicin resistant mutant strain of *E. ictaluri* was developed using a zebrafish isolate (LADL 11-194) for vaccine work. Zebrafish were obtained to screen for potential probiotic bacteria producing bacteriocins. Giant danios were obtained for use as a proxy for pharmacokinetic (drug dosing) studies. Commercial probiotic companies were contacted for product testing and delivery.

Results: Catfish and ornamental fish-derived isolates represent two discrete phyletic lineages**.** Within groups, isolates from catfish and ornamental fish were largely clonal, with few exceptions, indicating a high degree of genetic stability among *E. ictaluri* populations within each discrete industry. Live attenuated vaccines for *E. ictaluri* developed at LSU, ΔureG and ΔesrC, were prepared for inclusion in the study. Preliminary challenge trials with the disease-causing strains were unsuccessful with the initial population of zebrafish from Florida, potentially due to previous exposure to the disease or another vaccine. Optimal dosing with a good probability of successful treatment of an infection ranged from 2 to 4 mg/L for 60 mg/kg oral florfenicol, from 0.125 to 0.5 mg/L for 8 mg/kg oral enrofloxacin, and from 0.016 to 0.0625 mg/L for bath dosing (10 mg/L for 5 h) of enrofloxacin. We also demonstrate that the concentration of probiotics used in the dosing regimen are important in achieving microbiome shifts in the gastrointestinal system as Probiotic A (at a lower concentration) did not influence the species richness.

Outreach Overview: Five presentations to fish health and culture professionals and veterinary and graduate students were provided at four different meetings: the 46th Annual Meeting of the Mississippi Chapter of the American Fisheries Society (February 2020), the 45th Annual Meeting of the Mississippi Chapter of the American Fisheries Society (February 2019), the Virtual Conference of the International Association for Aquatic Animal Medicine (May 2021), and the American Fisheries Society Fish Health Section Summer Student Seminar Series (June 2021). An additional presentation on probiotic studies is scheduled for the Eastern Fish Health Workshop, April 2022. Refereed publications are currently in

preparation. Outreach has occurred through some discussions with individual farms, but outreach is also currently planned through industry newsletters and farmer meetings, additional one-on-one industry contacts, and extension publication updates.

Targeted Audiences: Catfish and ornamental fish producers, fish health professionals, Extension agents, broad scientific community

Outputs: There have been one journal article, one manuscript in preparation, two Masters theses, and six oral presentations to date.

Outcomes/Impacts: The results of this work demonstrate the isolates from ornamental fish are largely a clonal population with negligible genetic variability. Further, native plasmids among ornamental isolates were also consistent and harbored no recognized antibiotic resistance genes. This would indicate management practices (vaccines; probiotics; antimicrobial regimes) should be consistent across multiple isolates from different facilities and geographic regions. Live attenuated mutant strains which were not harmful to zebrafish in preliminary challenges could be developed successfully. Enrofloxacin and florfenicol drug studies using a closely related species, the giant danio, will help producers more accurately dose medicated feeds for effective disease treatment. Probiotics added to pond water will shift the intestinal bacterial communities of zebrafish, can enhance numbers of “good bacteria” and may help reduce losses from *E. ictaluri*.

Partnerships: Nothing to report.

Targeted Marketing Research and Outreach for Improving the Position of Southern Aquaculture Products in the Grocery Marketplace

Reporting Period: Jan. 1, 2021 - December 31, 2022
Length of Project: 3 Years
Current Project Year: 3
Total Funds Committed: $292,827
Principal Investigators: Ganesh Kumar, *Mississippi State University*; Jonathan van Senten, *Virginia Polytechnic Inst. and State University*; Madan Dey, *Texas State University*

Relevance: The U.S. seafood markets are highly competitive and diversified in terms of species sold and product forms. Domestic aquaculture producers have to be highly competitive to survive in this global marketplace dominated by imports. Domestic producers who are at the lower end of the supply chain are often unaware of the dynamic consumer interactions that occur in retail markets. Success in these dynamic and competitive environments can only be achieved by making effective marketing decisions. Such decisions rely on the availability of information about actual consumer behavior in retail markets as proper analysis of such downstream signals could help formulate effective marketing strategies. This is vital for improved positioning of southern aquaculture products.

Response: Seafood retail scanner data is one of the best sources of information that cover the magnitude, dynamism, and diversity of the U.S. seafood grocery markets. These big data are generated by scanning the Universal Product Code (UPC) or the barcode of the products. This project is aimed at tailoring marketing information relevant to the southern aquaculture industry by focusing on seafood sales in grocery stores and purchases of seafood at the household level in major markets. To examine retail market trends for seafood in the U.S., seafood scanner data (ScanTrack®) were purchased from A.C. Nielsen Consumer LLC. Later upon gathering insights from retail market analysis, the project purchased HomeScan® from A.C. Nielsen Consumer LLC to analyze consumer characteristics affecting retail purchases.

Results: The original purchase of the retail scanner data from AC Nielsen Consumer LLC was proposed for Year 1, Quarter 2 of the project (January 2021). However, inadvertent delays were experienced that delayed the purchase of the data for several months. Finally, the dataset was purchased and downloaded on September 13, 2021. Upon cleaning up the large dataset, the first effort was to develop retail market trends for general seafood products. This was followed by generating detailed retail market information for regionally important species such as catfish, trout, tilapia, oysters, and crayfish. Retail seafood sales amounted to $16.7 billion in the 2020-2021 time period registering an annual average growth rate of 8.1%, fueled mostly by the 21% increase in total the year after the onset of the COVID-19 pandemic. Shrimp, salmon, tuna, crab, and tilapia were the top five most-sold seafood categories in U.S. retail markets. The South Atlantic region had the greatest total sales and sales per capita among regions. New York City had the greatest total seafood sales, followed by Los Angeles and Philadelphia. U.S. farm-raised catfish was the only domestic aquaculture product sold in retail stores among the top ten seafood consumed (top 8th). Catfish registered an annual average growth of 5.8% while swai registered only 0.7% annual growth. Dallas/Fort Worth had the greatest total retail seafood sales for U.S. catfish products, followed by Chicago and St. Louis. Los Angeles was the most important

city for retail swai sales. Seattle/Tacoma Market had the greatest total retail seafood sales for trout products followed by Portland (OR) and Atlanta. St. Louis and Atlanta were two cities that registered relatively higher growth rates for both catfish and trout products. About 72% of trout products sold in U.S. retail markets are steelhead trout products. Rainbow trout prices increased by 12% annually in contrast to those for steelhead trout which were relatively constant. Seafood products sold in retail groceries including catfish and trout were mostly sold in small packages (1-2 lb packs). Frozen and refrigerated seafood was the most popular product form sold in grocery stores. Analysis of the HomeScan® data is ongoing as well as detailing retail market trends for tilapia and oyster products. The econometric analysis provided insights into the inverse relationship between retail seafood prices and the quantities demanded. Product form, package size, promotion, region, and seasonality were found to influence seafood demand at the retail stores.

Outreach Overview: Three separate industry-specific reports have been generated and disseminated to stakeholders. Five presentations, including 3 at stakeholder meetings of catfish and trout, have been made.

Targeted Audiences: The targeted audience includes aquaculture producers and processors in the southern region, policymakers, researchers, industry organizations, congressional members and staff, and the general public.

Outputs: Three peer-reviewed manuscripts, 5 presentations, as well as four separate industry-specific reports were generated as part of this project.

Outcomes/Impacts: The ultimate impact of this ongoing study cannot be estimated at this moment.

Partnerships Developed: Leslie Noel Sturmer, Shellfish Aquaculture Extension Specialist, University of Florida; Lianqun Sun, Post Doctoral Research Associate Mississippi State University; and Matt Parker, Extension specialist, University of Maryland.

Evaluation of Probiotics and Prebiotics in Finfish Hatcheries to Improve Larval Production

Reporting Period: Dec. 1, 2021 – Dec. 31, 2022
Length of Project: 2 Years
Current Project Year: Completed
Total Funds Committed: $167,837
Principal Investigators: Delbert Gatlin and Todd Sink, *Texas A&M University*; Mike Frinsko, Steven Hall, Craig Harms, and Harry Daniels, *North Carolina State University*; Robert Vega, *Texas Parks and Wildlife*; Lou D'Abramo, *University of Alabama at Birmingham*

Relevance: Poor and unpredictable hatchery production can be a major impasse to the development and enhancement of marine fish aquaculture in the United States. Due to numerous common challenges in hatchery operation, including undesirable conditions such as overcrowding and poor water quality, elevated fish mortalities are often encountered. Thus, both probiotics and prebiotics were evaluated in an effort to improve early rearing survival, as well as enhance subsequent fish growth and immunity.

Response: This collaborative project, involving researchers at four different Southern regional institutions, has focused on the evaluation of two commercially available probiotics (Aquaculture Blend from Bio-Cat and Bactocell from Lallemand) and two commercially available prebiotics (GroBiotic®-A from International Ingredient Corporation and SiLO Health® from BASF, Germany). These supplements have been evaluated by administering individually during hatchery production trials of domesticated striped bass, red drum, and Southern flounder.

Results: Several different lines of investigation have been pursued in this project and have provided assorted results, some which related directly to prebiotic and probiotic administration, and others to different aspects of larval fish rearing. The administration of prebiotics and probiotics to rotifers was developed such that changes in the microbial composition of these live food organisms was achieved. Significant improvements in swimbladder inflation of domesticated striped bass has been achieved through a combination of techniques. In addition, advances in automatic feeders for administering Artemia have been made and will enhance the precision by which feeding occurs in larval rearing of domesticated striped bass.

Outreach Activity: It is anticipated that results of these various project activities will be of particular interest to anyone culturing larval fish species. Results of this project will be distributed to aquaculturists through various mechanisms including Extension meetings, refereed journal publications, articles in trade journals, and conferences.

Targeted Audience: Aquaculturists working at state and federal fish hatcheries, as well as commercial facilities in which culture of fish species through larval stages is conducted.

Outputs: Specific outputs from this project to date have been in the form of workshops in which the larval rearing techniques employed in this project were described and evaluated.

Outcome/Impacts: Outcomes/impacts have not been achieved to date because many of the techniques evaluated at experimental scale have not been extended to hatchery production at larger scale. Although such activities were planned, they were largely curtailed by the COVID-19 pandemic that occurred during the course of this project.

Partnerships:

Texas A&M University

Texas Parks and Wildlife Department
Type: Government
Level: State
Nature of partnership: Provided larval red drum and southern flounder for the research; assisted with research trials.

North Carolina State University

Pamlico Aquaculture Field Laboratory
Type: Government
Level: University
Nature of partnership: Provided larval domesticated striped

Publications, Videos, and Computer Software

Reporting Period: Jan. 1, 2020 – Sept. 30, 2022
Length of Project: March 1, 1995 – Ongoing
Current Project Year: 24 & 25
Total Funds Committed: $38,763
Principal Investigator: Todd Sink, *Texas A&M University*

Relevance: When this project was initiated, fewer than half the states had educational materials covering the major aquacultural species in their state. The concept of using the SRAC program to produce timely, high-quality educational materials is based upon the benefits of centralizing the production process while using a region-wide pool of expertise to develop materials. Distribution is then decentralized through the SRAC publications and SRAC-aquaponics websites, SRAC YouTube channel, and nationwide network of Extension Specialists and County Agents including the National eXtension Initiative. This process assures an efficient publication process that makes use of the best available talent in specific subject areas.

Response: A committee of Extension specialists and researchers solicit input on publication and digital product needs from their counterparts across the region. These suggestions are prioritized during an annual meeting of the publications committee based on need and available funding. The best talents from within and outside the region are then recruited to submit proposals to develop these products.

Results: The result is widespread availability of high-quality educational materials for scientists, educators, producers, students, and the public which in turn leads to increased or improved efficiency aquaculture production, improved awareness of aquaculture products and the nutritional benefits of seafood, and increased aquaculture investment.

Outreach Overview: SRAC factsheets and videos are distributed electronically, by direct request, and via Extension Specialists, County Extension Agents, and other RACs. These products are used regularly by clientele in all 50 states as well as internationally in 217 countries and territories. Factsheet, videos, and web presentations are accessed daily from the SRAC publications and SRAC-aquaponics websites and SRAC YouTube channel by people searching for technical information.

Targeted Audiences: The target audiences for this project are educators, consumers, producers, potential aquaculture investors, students, and the public.

Outputs: Nine new fact sheets are in development, have been received, and are in the editorial process. All completed publications have been distributed electronically throughout the Southern Region and to interested Extension Specialists in other regions.

Outcomes/Impacts: Publications and videos produced by SRAC are increasingly used in educating high school and college students about aquaculture. These programs heavily utilize SRAC publications and videos for educational purposes, but usage is impossible to measure because access to the information is gained from many different Internet sites, through file sharing, and digital downloads of PDFs.

Another important impact is the education of local, state, and federal regulators about the aquaculture industry. This impact is difficult to measure but feedback from personnel in two states have indicated that the fact sheets are recommended reading for all new employees dealing with aquaculture, water quality, exotic species, and other permitting duties. This should be a positive influence toward making aquaculturists better understood and the development of more enlightened regulations.

The impact on consumers of aquaculture products is also likely significant. Consumers are primarily interested in a wholesome, safe, and inexpensive product, and according to usage analytics the consumer information series fact sheets and videos developed within SRAC have generated more interest than the producer-directed materials. The fact sheets are in demand in both the English and Spanish versions, and as more information becomes available, extension materials on food safety are experiencing increased demand by health-conscious consumers.

The Southern Regional Aquaculture Center commenced the Publications, Videos, and Computer Software Project in order to provide these materials in a timely and relevant manner. Since that time, more 358 technical fact sheets (248 in the current catalog), 102 update revisions, 7 web presentations, 7 software programs or web tools, and 31 videos have been produced through the SRAC PVCS Project. In the current reporting period alone, **183,321*** unique users from **213*** countries and territories used the SRAC Publications website, https://srac.tamu.edu/, to view or download SRAC publications **309,239*** times. SRAC videos were viewed on the SRAC YouTube channel **13,297*** times during the current reporting period. The AquaPant website, created with funding from the SRAC PVCS Project, had 766,329* unique users that viewed 2,995,270* webpages during the reporting period. These users were from 218* countries/territories. These analytics demonstrate that the SRAC Publications, Videos, and Computer Software project truly has worldwide reach and impact. *Web-based analytical tracking and reporting methods.

Development of Rapid Detection Methods for Emerging Aquatic Animal Pathogens Threatening Southern Region Aquaculture

Reporting Period: Jan. 1, 2022 – Dec. 31, 2022
Length of Project: 2 Years
Current Project Year: 1
Total Funds Committed: $198,355
Principal Investigators: Matt Griffin, *Mississippi State University*; Tanya Darden, *South Carolina Department of Natural Resources*; and Thomas Waltzek, *University of Florida*

Relevance: Iridoviruses (i.e., megalocytiviruses) negatively impact Florida ornamental aquaculture. Despite the impact of iridoviruses on Florida aquaculture, a simple (pondside), rapid, and economical diagnostic test for detecting megalocytivirus are unavailable to Florida ornamental fish farmers. Similarly, *Roseovarius* Oyster Disease (ROD) is a major disease of eastern oysters and has caused seasonal mortality events, up to 90% in first year hatchery-reared crops, in the Northeast. Using microscopy, the manifestation of the disease has been found to coincide with the presence of the bacteria, *Aliiroseovarius crassostreae*. Despite knowledge about the causative agent of ROD, there is still no reliable standard diagnostics to test for the presence of the pathogen. Likewise, *Erysipelothrix* spp. are Gram-positive bacteria that can infect a variety of hosts including mammals, fish, birds, reptiles and insects. While *Erysipelothrix* spp. are generally considered commensal organisms in fish, outbreaks of piscine erysipelas caused by *Erysipelothrix piscisicarius* have been reported from the US ornamental aquaculture industry and *E. piscisicarius* was found in a survey of western mosquitofish (*Gambusia affinis*) from catfish aquaculture ponds. There is an urgent industry defined need for rapid, sensitive methods to detect these pathogens in their hosts and environments.

Response: Using comparative genomics, unique regions in the megalocytivirus and *A. crassostreae* genomes were identified. Real-time, quantitative PCR (qPCR) primers and probes have been developed and validated for both megalocytivirus and *A. crassostreae*, thus providing rapid, highly sensitive methods for detecting pathogens in the environment and host tissues. Likewise, the genomes of 23 *Erysipelothrix* spp. isolates from aquatic animals have now been sequenced to identify similar, discriminatory targets for *E. piscisicarius* and assay validation will proceed accordingly.

Results: These assays will advance aquaculture production in the short and long term by providing means to confirm fish/oysters imported or raised by farmers are free of these pathogens, while improving biosecurity. Additionally, these assays, once fully validated, can be implemented in state and national surveillance efforts to assess the impact of megalocytivirus, *A. crassostreae* and *E. piscisicarius* in US aquaculture.

Outreach Activity: None to date.

Targeted Audience: Targeted audiences include aquaculturists, aquatic animal health professionals, policyvmakers, researchers, industry organizations, congressional members and staff, and the general public.

Outputs: There have been two oral presentations, one journal article, and two Ph.D. dissertations completed to date.

Outcome/Impacts: Rapid, highly sensitive qPCR assays have been developed and validated for megalocytivirus and *A. crassostreae*. Meanwhile, genomes of multiple *Erysipelothrix* spp. from aquatic animals have been sequenced to identify similar, discriminatory targets for *E. piscisicarius*, which will facilitate development of a similar, rapid, highly sensitive assay for *E. piscisicarius*.

Partnerships: None to date.

Identification of Novel Flavobacterium Columnare Vaccine Candidates for Catfish and Other Aquaculture Fish Species in the Southern Region

Reporting Period: Jan. 1, 2022 – Dec. 31, 2022
Length of Project: 3 Years
Current Project Year: 2
Total Funds Committed: $299,653
Principal Investigators: Timothy Bruce (PI), *Auburn University*; Matt Griffin, *Mississippi State University*; Thomas Loch, *Michigan State University*; Esteban Soto, *University of California-Davis*; Benjamin LaFrentz, *USDA-ARS Aquatic Animal Health Research Unit*

Relevance: Columnaris disease is a leading pathogen in global aquaculture. In the southeastern United States, columnaris disease is responsible for significant losses in the catfish industry, along with other economically important fish species. The development of an efficacious vaccine to prevent and control columnaris disease has been restricted partially due to a lack of understanding of the broad genetic diversity of columnaris-causing bacteria. *Flavobacterium columnare*, once thought to be the only species of bacteria to cause columnaris disease, now represents four distinct species of columnaris-causing bacteria: *F. columnare*, *F. covae*, *F. davisii*, and *F. oreochromis*, formerly genetic groups 1, 2, 3, and 4, respectively. One reason for the lack of efficacy is the sub-optimal host-pathogen dynamics. With the recent advancements in our understanding of columnaris causing bacterial genetic diversity, we hypothesize that this new information will aid in developing an efficacious live-attenuated vaccine for use in catfish and other southern region aquaculture fish species to prevent columnaris disease.

Response: To date, our team has developed eighteen rifampicin-resistant strains of *F. columnare*, *F. covae*, *F. davisii,* and *F. oreochromis*. Several of these (n = 5) have been confirmed to be attenuated and lacking the ability to cause disease. These strains can serve as a live-attenuated vaccine against columnaris disease in either catfish, tilapia, rainbow trout or baitfish.

Results: Five virulent columnaris-causing bacteria isolated have been confirmed attenuated in channel catfish, Nile tilapia, and rainbow trout.

Outreach Activity: To date, we have presented several project overviews at scientific conferences. A popular article has also been published in the Alabama Fish Farming News and distributed to catfish producers. We also plan to publish results in peer-reviewed journals throughout the project period.

Targeted Audience: Southern region fish producers, extension specialists, aquaculture researchers, and fish health experts.

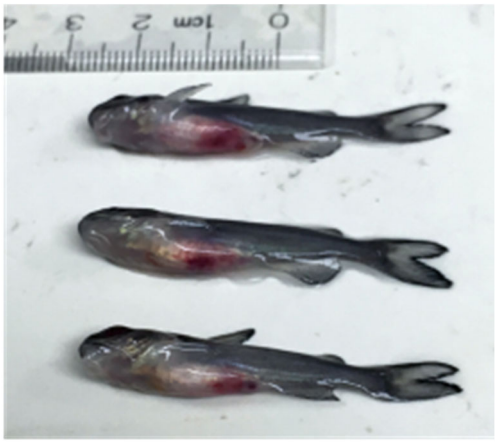
Outputs: Outputs generated during this reporting period include the development of eighteen rifampicin-resistant strains of columnaris-causing bacteria. Additionally, five of these strains have been confirmed to be attenuated through in vivo virulence assessment. Mutations potentially contributing to rifampicin resistance and attenuation have been assessed through genome comparisons for eight

rifampicin-resistant strains. There have been four oral presentations, one Extension/outreach publication, and one journal article to date.

Outcome/Impacts: Outcomes to date include the generation of eighteen rifampicin-resistant strains of columnaris-causing bacteria, five of which have been confirmed to be attenuated and are currently being tested for use as effective live vaccines. Within this reporting period, five virulence trials for rifampicin-resistant *F. covae* strains were conducted, along with four *F. oreochromis* trials, four *F. columnare* trials, and six *F. davisii* trials. Research is ongoing to determine whether the remaining rifampicin-resistant strains are attenuated. Our research aims to produce an efficacious vaccine for economically important fish species in the southern region to minimize loss due to columnaris disease.

Partnerships: Partners have yet to be generated during this reporting period.

Investigating the Emergence of Vibriosis in Catfish Hatcheries in the Mississippi Delta



Reporting Period: Feb. 1, 2021 – Dec. 31, 2022
Length of Project: 2 Years
Current Project Year: 2
Total Funds Committed: $56,009
Principal Investigators: Matt Griffin, *Mississippi State University*; Al Camus, *University of Georgia*; Frank Stewart, *Montana State University*

Relevance: Over the past several years, Vibriosis caused by *Vibrio* spp. has been identified as a cause of isolated losses in catfish hatcheries located in the Mississippi Delta. These isolates are biochemically consistent with *V. cholerae* but appear genetically distinct from strains associated with human disease, consistent with anecdotal reports of Vibriosis in other cultured and wild fish species. Preliminary research has shown a high degree of genetic variability among isolates from infected catfish fry suggesting the existence of multiple genetic variants. A better understanding of the identity of these genetic variants and their source of origin is essential. Hence, it is critical to identify suitable genetic markers and develop a molecular based assay that can differentiate these strains from other environmental *Vibrio* spp., as well as document differences between fish associated strains and toxigenic *V. cholerae*. Collection of bacterial isolates and development of methods for rapid detection in fish tissues and the environment will be valuable in determining modes of transmission and sources of contamination in catfish hatcheries.

Response: A comparative analysis was performed on ~70 suspected *Vibrio* spp. from cooperating fish health laboratories in North America. A histopathological assessment was performed on fish from a naturally occurring outbreak in a cooperating fish hatchery. Lastly, samples (catfish digesta, catfish eggs, water from brood ponds) were collected over the course of two years and subjected to microbial community profiling using deep amplicon sequencing targeting the 16S rRNA gene to identify the potential point source of *V. cholerae* in catfish hatcheries.

Results: Isolates associated with spontaneous mortality events in catfish hatcheries have been identified as non-toxigenic *V. cholerae*, lacking the molecular machinery required to produce cholera toxin (CTX). Histopathological assessments indicate disease begins within the intestinal tract, spreading through the intestinal wall, ultimately resulting in a generalized bloodborne infection. Efforts to identify the source of contagion have produced mixed results. DNA has been extracted and 16S metagenomes sequenced for over 200 catfish samples including catfish digesta, gut contents, eggs and water samples. In addition to these samples, DNA has been extracted from an additional 196 catfish digesta, egg, and water samples, for which analysis is ongoing. The current data indicates that there has been little presence of bacterial species from the *Vibrio* genus; consistent with the lack of outbreaks during sampling. However, multiple other potentially pathogenic bacteria found in relatively high abundance in these samples. This census of the catfish egg microbiome is the most comprehensive study of this type to date and lays a foundation for investigating the influence of the egg microbiome on fish health in the hatchery.

Outreach Activity: None to date.

Targeted Audience: Catfish producers, fish health professionals, aquaculture extension agents, regulatory agencies, etc.

Outputs: There has been one oral presentation to date.

Outcome/Impacts: Isolates recovered from spontaneous mortality events have been identified as *V. cholera* by multiple genetic and phenotypic methods, including multi-locus sequence typing and genomics. These isolates have been identified as non-toxigenic or non-cholera V. cholerae, as all isolates from catfish hatcheries have been negative for the cholera toxin (CTX) gene. In response to repeated annual outbreaks of Vibriosis in catfish hatcheries, producers have reduced the biomass they are carrying in hatcheries as well as made more concerted efforts to avoid holding fish for extended periods. These efforts appear to have reduced incidence of Vibriosis in catfish hatcheries in the Mississippi Delta. While this has complicated this research effort, incidence of *V. cholerae* in catfish hatcheries has been significantly reduced over the past 2-3 years.

Partnerships: USDA Warmwater Aquaculture Research Unit provided source of eggs and fish for *Vibrio* sampling; provided sequencing support for genome sequencing

Products Developed and Students Supported

Journal Articles and Abstracts

Hegde, S., Kumar, G., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2022). Economic contribution of the U.S. catfish industry. Aquaculture Economics & Management, 26(4), 384-413.

Hegde, S., Kumar, G., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. 2022. Technological progress in the US catfish industry (2022). Journal of World Aquaculture Society, 53(2), 367-383.

Jimmy Avery, Shraddha Hedge and Ganesh Kumar. 2022. U.S. Catfish Production Is Becoming More Efficient. World Aquaculture Society, 52(3).

López-Porras A, Griffin M. J, Armwood A. R, Camus A. C, Waldbieser G. C, Ware C, Richardson B, Greenway T. E, Rosser T. G, Aarattuthodi S, and Wise D. J. 2022. Cross-protective efficacy of the *Edwardsiella ictaluri* vaccine against *Edwardsiella piscicida* infection in catfish. Journal of Fish Diseases. DOI: 10.1111/jfd.13623. Journal of Fish Diseases, Volume: 45, Issue: 7, Pages: 1001-1010, First published: 25 April 2022, DOI: (10.1111/jfd.13623)

López-Porras A, Griffin M. J, Armwood A. R, Camus A. C, Waldbieser G. C, Ware C, Richardson B, Greenway T. E, Rosser T. G, Aarattuthodiyil S, and Wise D.J. 2021. Genetic variability of *Edwardsiella piscicida* isolates from Mississippi catfish aquaculture with an assessment of virulence in channel and channel × blue hybrid catfish. Journal of Fish Diseases. 44(11):1725-1751. DOI: 10.1111/jfd.13491.

Johnson, Divya. "Phenotypic and genotypic characterization and comparison of *Edwardsiella ictaluri* isolates derived from catfish and ornamental fish species" (2021). MS Thesis. Mississippi State University, Mississippi State, MS USA.

Malbrough, Brandy L, “Evaluating vaccine management strategies for *Edwardsiella ictaluri* infections in zebrafish (Danio rerio)” (2023). MS Thesis. Louisiana State University, Baton Rouge, LA USA.

Vorbach B.S., J. Zhou, Y. Lang, J.B. Bulitta, and R.P.E. Yanong. 2024. (online 2023) Population pharmacokinetics of enrofloxacin and florfenicol in the giant danio (*Devario aequipinnatus*) following oral administration of both antibiotics and bath administration of enrofloxacin. Aquaculture 579.

Brammer-Robbins E., E.K. Freeman, A.S. Kanarek, J.H. Bisesi, E. J. Cassiano, Q.M. Tuckett, R. P. E. Yanong, and C.J. Martyniuk. Assessing the use of probiotic treatments in the management of Edwardsiella ictaluri occurrence and their effects on gastrointestinal microbiota composition in farmed zebrafish (*Danio rerio*). Manuscript in prep.

Sun, L., Engle, C., Kumar, G., & van Senten, J. 2022a. Retail market trends for seafood in the United States. Journal of the World Aquaculture Society, 1– 22. https://doi.org/10.1111/jwas.12919

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022b. Retail market trends for US catfish and swai products in the United States. Aquaculture Economics & Management, 1-21. https://doi.org/10.1080/13657305.2022.2147250.

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2023. Supermarket trends for rainbow and steelhead trout products: Evidence from scanner data, Aquaculture Reports, 30, 101579. https://doi.org/10.1016/j.aqrep.2023.101579.

Koda, S. A., Subramaniam, K., Hick, P. M., Hall, E., Waltzek, T. B., & Becker, J. A. 2023. Partial validation of a TaqMan quantitative polymerase chain reaction for the detection of the three genotypes of Infectious spleen and kidney necrosis virus. PloS one, 18(2), e0281292.

Harrison, C.E., LaFrentz, B.R., Peatman, E., Bruce, T.J. An overview of vaccine development strategies for columnaris-causing bacteria in cultured fish species. In progress.

Extension/Outreach Publications

Hegde, S., Kumar, G., Engle, C. R., Hanson, T. R., Roy. 2022. Catfish industry contribution. Catfish Journal, January 2022.

Kumar, G., and J. Avery. 2018. Effective communication portals for technology transfer. 2018 Delta Research and Extension Center Annual Report.

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022a. Retail market trends for US catfish and swai products in the United States. Report prepared for the US catfish processors. (~95 pages).

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022b. Retail market trends for trout products. Report prepared for the US trout farmers. (~75 pages)

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022c. Retail market trends for tilapia products. Report prepared for the US tilapia producers. (~75 pages).

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2023. Retail market trends for oysters. Report prepared for the US oyster growers. (~65 pages).

Kumar, G. 2022. Seafood market trends in retail marketplaces, MASGC Newsletter, September 2022.

Harrison, C.E., LaFrentz, B.R., Bruce, T.J. Development of an attenuated columnaris vaccine for catfish and other fish species in the southern region. Alabama Fish Farming Center, Fish Farming News, 2022(1):1-16.

Workshops

Sink, T. 2022. A live Feeds Harvesting System for Production of Warmwater Marine Finfish. Lake Jackson, TX (demonstration project; 14 participants)

Sink, T. 2021 and 2022. A live Feeds Harvesting System for Production of Warmwater Marine Finfish. College Station, TX (demonstration project; 26 total participants)

Peer-reviewed Fact Sheets (In development)

Revision of SRAC 322: Red Drum: Production of Foodfish

Revision of SRAC 0479b: Columnaris Disease: Flavobacterium columnare

Revision of SRAC 0451: Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations

Revision of SRAC 0452; Recirculating Aquaculture Systems: Management of Recirculating Aquaculture Systems

Revision of SRAC 0392: Transportation of Warmwater Fish: Procedures and Loading Rates combined with SRAC 0393

Revision of SRAC 0393: Transportation of Warmwater Fish: Loading Rates and Tips by Species combined with SRAC 0392

Revision of SRAC 0423: Determining Sexual Maturity of Broodstock for Induced Spawning of Fish

Revision of SRAC 0401: Controlling Bird Predation at Aquaculture Facilities: Frightening Techniques

Revision of SRAC 0400: Avian Predators at Aquaculture facilities in the Southern United States

Oral Presentations

Broach, J.S., A. Watson, E. Levesque, J. Morgenstern, and E. Bowman. 2023. Evaluation of the potential to reduce Artemia levels during the larval phase of marine baitfish. Aquaculture America 2023, New Orleans, LA.

Gatlin, D. M., III, B. A. Candelaria and F. Y. Yamamoto. 2022. Evaluating various nutritional enrichments of rotifers *Branchionus* sp. Aquaculture America 2022, San Diego, CA.

Kumar, G. 2022. Economic impact of the U.S. catfish industry. Catfish Farmers of America. New Orleans, March 2022.

Kumar, G. 2022. Technology progress and factors influencing production in intensive production systems in the U.S. catfish industry. Catfish Farmers of America. New Orleans, March 2022.

Shraddha Hegde, Ganesh Kumar, Carole Engle, Terry Hanson, Luke A. Roy, Morgan Cheatham, Jimmy Avery, Suja Aarattuthodi, Jonathan van Senten, Jeff Johnson, David Wise, Sunni Dahl, Larry Dorman, and Mark Peterman. 2022. Technological progress in the U.S. catfish industry. World Aquaculture Society Meeting, San Diego, California, March 2022.

Shraddha Hegde, Ganesh Kumar, Carole Engle, Terry Hanson, Luke A. Roy, Jonathan van Senten, Jeff Johnson, Jimmy Avery, Suja Aarattuthodi, Sunni Dahl, Larry Dorman, and Mark Peterman. 2022. Economic contribution of the US catfish industry. World Aquaculture Society Meeting, San Diego California, March 2022.

Hanson, T. R., Hegde, S., Kumar, G., Engle, C. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2021). Economic contribution of the U.S. catfish industry. Annual producer meeting of West Alabama catfish farmers. Greensboro, AL. Dec 2021.

Hegde, S., Kumar, G., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2021). Economic contribution of the U.S. catfish industry. World Aquaculture Society Meeting, San Antonio, Texas August 2021.

Cheatham, M. C., *Hegde, S., Kumar, G., Engle, Hanson, T., Roy. L, and van Senten, J (2021). Technological progress in US catfish farms. World Aquaculture Society Meeting, San Antonio, Texas August 2021.

Kumar, G., Hegde, S., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2021). Economic contribution of the U.S. catfish industry. NWAC Fall seminar, Stoneville, MS. November 2021

Kumar, G., Hegde, S., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2021). Economic contribution of the U.S. catfish industry. Auburn Fall seminar, Greensboro, AL. December 2021

Kumar, G., Hegde, S., Engle, C. R., Hanson, T. R., Roy, L. A., van Senten, J., Johnson, J. W., Avery, J. L., Aarattuthodi, S., Dahl, S., Dorman L., & Peterman, P. (2021). Economic contribution of the U.S. catfish industry. NWAC Fall seminar, Columbus, MS. December 2021.

Cheatham, M. C., Hegde, S., Kumar, G., Engle, Hanson, T., Roy. L, and van Senten, J (2021). Technological progress in US catfish farms. NWAC Fall seminar, Columbus, MS. December 2021.

Hegde, S., G. Kumar, C. R. Engle, T. Hanson, J. van Senten, and L. Roy. 2021. Economic impact assessment of the U.S. catfish industry. 2021 Graduate Research Symposium, Mississippi State University. October 2021.

Kumar, G., 2019. Factors affecting the adoption of aquaculture technologies. Asia Pacific Aquaculture Chennai, India. May 2019.

Kumar, G., C. R. Engle, *S. Hegde, J. van Senten, S. Aarattuthodiyil, J. L. Avery. 2019. Assessment of economic impact and cost of regulations on catfish farms. Fall seminar, Mississippi State University, Stoneville, MS. Nov 2019.

Kumar, G., L. A. Roy, and T. R. Hanson. 2019. Cost of regulations, technological advances, and Economic impact: Research planned for the catfish industry. Annual producer meeting of West Alabama catfish farmers. Greensboro, AL. Dec 2019.

López-Porras A, Griffin M. J, Wise, D. J, Rosser T. G, and Aarattuthodiyil, S. 2019. Intraspecific genetic variability of *Edwardsiella piscicida* recovered from Mississippi catfish aquaculture and assessment of virulence in channel and channel x blue hybrid catfish. Eastern Fish Health Workshop. Lake Placid, New York.

López-Porras A, Griffin M. J, Wise, D. J, Rosser T. G, and Aarattuthodiyil, S. 2020. A live-attenuated *E. ictaluri* vaccine protects channel and hybrid catfish fingerlings against heterologous *Edwardsiella piscicida* challenge. Eastern Fish Health Workshop. Shepherdstown, West Virginia.

Poudel A, Koshy M. C, Khoo L, Lawrence M, Kumar G, Peterman M, and Aarattuthodi S. 2022. Effect of low dissolved oxygen on the pathogenesis of *Edwardsiella piscicida* in channel and hybrid catfish. Aquaculture 2022. World Aquaculture Society conference. San Diego, California.

Poudel A, Khoo L, Lawrence M, Kumar G, Hawke J, Dorman L, Ramena G, and Aarattuthodi S. 2022. Phenotypic characterization of *Edwardsiella piscicida* isolates from catfish aquaculture. Aquaculture 2022. World Aquaculture Society conference. San Diego, California.

Poudel A, Ganesh K, Khoo L, Lawrence M, and Aarattuthodi S. 2021. Phenotypic characterization of *Edwardsiella piscicida* isolates derived from catfish aquaculture. Marine Biology and Aquaculture. Virtual seminar. September 23, 2021.

Johnson, D., M. J. Griffin, L. H. Khoo, G. C. Waldbieser, and S. Aarattuthodi. Molecular characterization of *Edwardsiella ictaluri* isolates and efficacy of E. ictaluri vaccine to protect channel catfish fingerlings against the field isolates. 45th Annual meeting of Mississippi Chapter of American Fisheries Society. February 20-22, 2019 in Jackson, MS.

Johnson, D., M. J. Griffin, L. H. Khoo, G. C. Waldbieser, and S. Aarattuthodi. Biological, molecular and serological characterization of *E. ictaluri* isolates in catfish and ornamental fish species. 46th annual meeting of Mississippi Chapter of the American Fisheries Society. February 12-14, 2020 in Gulfport, MS.

Brammer-Robbins EM, Freeman EK, Kanarek AS, Bisesi JH Jr., Cassiano EJ, Tuckett QM, Yanong RPE, Martyniuk, CJ. 2021. Evaluating Probiotic Treatments in the Ornamental Fish Aquaculture Industry: Implications for Managing *Edwardsiella ictaluri* Outbreaks and Fish Microbiota. International Association for Aquatic Animal Medicine, IAAAM, May 22-26, Virtual Conference.

Johnson, D., M. J. Griffin, E. T. Woodyard, L. H. Khoo, G. C. Waldbieser, R. P. E. Yanong, J. P. Hawke and S. Aarattuthodi. 2021. Phenotypic and genotypic characterization and comparison of *Edwardsiella ictaluri* isolates derived from catfish and ornamental fish species. AFS-FHS Summer Student Seminar Series. Oral Presentation.

Brammer-Robbins EM, Freeman EK, Kanarek AS, Bisesi JH Jr., Cassiano EJ, Tuckett QM, Yanong RPE, Martyniuk, CJ. 2022. Assessing the Role of Probiotic Treatments in the Management of *Edwardsiella ictaluri* and Gastrointestinal Microbiota in the Ornamental Fish Aquaculture Industry. International Association for Aquatic Animal Medicine, IAAAM Annual Conference, May 16-18th, Virtual Conference.

Kumar, G., Sun, L., Engle, C., & van Senten, J. 2022. Retail market trends for trout products in the United States. Annual trout farmers meeting, Idaho Falls, Idaho, September 2022.

Kumar, G., Sun, L., Engle, C., & van Senten, J. 2022. Seafood market trends in the United States. National Aquaculture Extension Conference, Portland, Maine July 2022.

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022. Retail seafood market trends in the U.S. World Aquaculture Society Meeting, San Diego California, March 2022.

Sun, L., Kumar, G., Engle, C., & van Senten, J. 2022. Retail seafood market trends for catfish and Swai products. NWAC Fall seminar, Stoneville MS. November 2022.

Kumar G. 2022. Production and market research update. East MS catfish Fall seminar, Macon MS. December 2022.

Clark, G., D. M. Gatlin III. 2019. Evaluation of palatability enhancers in plant-based diets with juvenile red drum (*Sciaenops ocellatus*). World Aquaculture 2019, New Orleans, LA.

Lengxob Yong, Peter Kingsley-Smith, Ryan Carnegie, Tanya Darden. A Novel and Rapid qPCR Assay for Detection of Roseovarius Oyster Disease (ROD) Pathogen, *Aliiroseovarius crassostreae*, in Eastern Oyster (*C. virginica*). Southern Division American Fisheries Society, Norfolk, Virginia. 4 February 2023.

Lengxob Yong, Peter Kingsley-Smith, Ryan Carnegie, Tanya Darden. A Novel and Rapid qPCR Assay for Detection of Roseovarius Oyster Disease (ROD) Pathogen, *Aliiroseovarius crassostreae*, in Eastern Oyster (*C. virginica*). National Shellfisheries Association, Baltimore, Maryland. 27 March 2023.

Harrison, C.E., LaFrentz, B.R., Griffin, M.J., Loch, T.P., Soto, E., Bruce, T.J. Columnaris-causing bacteria vaccine development for catfish and tilapia. Eastern Fish Health Workshop, Atlantic Beach, NC. March 27-31, 2023.

Harrison, C.E., LaFrentz, B.R., Griffin, M.J., Loch, T.P., Soto, E., Bruce, T.J. Identification of columnaris disease vaccine candidates for catfish and other aquaculture fish species in the southern region. World Aquaculture Society-Aquaculture America, New Orleans, LA. February 23-26, 2023.

Bruce, T.J. An overview of columnaris disease in culture U.S. finfish: Experimental infections, disease diagnostics, and current treatments. International Symposium on Aquatic Animal Health (ISAAH). Santiago, Chile. September 5-8, 2022.

Harrison, C.E., LaFrentz, B.R., Griffin, M.J., Loch, T.P., Soto, E., Bruce, T.J. Identification of columnaris disease vaccine candidates for catfish and other aquaculture fish species in the southern region. American Fisheries Society Fish Health Online Seminar Series. July 28, 2022.

Wise, A., C. Ware, A. C. Camus, L. H. Khoo, G. C. Waldbieser and M. J. Griffin. Genetic characterization of *Vibrio* species isolated from commercially cultured fish. AFS-FHS Virtual Summer Seminar Series. Online. June 2021.

Sink, T. 2021. Tripletail, Bermuda chub, spadefish, and Atlantic croaker: New species under investigation for culture at Texas A&M university. Aquaculture America. San Antonio, TX

Sink, T., E. Silvy, and G. Stamport. 2022. A live feeds harvesting system for production of warmwater marine finfish. Texas Chapter of the American Fisheries Society. Hunt, TX

Poster Presentations

Johnson, Davida, Hu, Ruixue, Nguyen, Diem Thu, Griffin, Matt, Aarattuthodi, Suja, Camus, Alvin, Henderson, Eileen, and Soto,Esteban. Cross protective capabilities of an *Edwardsiella ictaluri* live attenuated vaccine against *E. piscicida* infection in a Nile tilapia (*Oreochromis niloticus*) model of infection. Star summer program symposium. University of California-Davis. August 27, 2021.

Vorbach, B.S., J. Bulitta, J. Zhou, Y. Lang, and R.P.E. Yanong. 2021. Pharmacokinetics and pharmacodynamics of enrofloxacin and florfenicol in the giant danio (*Devario aequipinnatus*) following oral and bath administration. International Association for Aquatic Animal Medicine, Virtual Conference. Poster Session. Online. May.

Digital Products

SRAC Home Website: www.srac.msstate.edu

SRAC Publications Website: https://srac.tamu.edu/

SRAC Aquaponics Website: https://srac-aquaponics.tamu.edu/

SRAC YouTube Channel: https://www.youtube.com/channel/UC1VFn_Lef2WdHFEVF1O82jA

AquaPlant Website: http://aquaplant.tamu.edu/

Students Supported

Caitlin Older. USDA Warmwater Aquaculture Research Unit, Post-doctoral fellow.

Noor-ul-Huda. Mississippi State University, Post-doctoral fellow.

Manoj Chandy Koshy. Mississippi State University, Post-doctoral fellow.

Shradda Hegde. Mississippi State University, Ph.D. Student. Graduated: December 2021. Dissertation title: *Economic aspects of the U.S. catfish farming: Adoption of technologies, cost of regulations, and economic impact.*

Samantha Koda. University of Florida, Ph.D. Student. Graduated. Dissertation title: *Megalocytiviruses in aquaculture: Genetic diversity, improved molecular diagnostic tools, and the development of an experimental challenge model to determine the effect of water temperature on disease.*

Ashmita Poudel. Mississippi State University, Ph.D. Student. Graduated: 2023. Dissertation title: *Epidemiology of Edwardsiella piscicida and economic loss assessment due to E. piscicida and E. ictaluri in catfish aquaculture.*

Courtney Harrison. Auburn University, Ph.D. Student. Anticipated date of completion: Spring 2025. Dissertation title: *Columnaris-causing bacteria vaccine development for catfish and tilapia.*

Divya Rose. Mississippi State University, Ph.D. Student. Anticipated date of completion: Spring 2025. Dissertation title: TBD.

Madeline Brown. Montana State University, Ph.D. Student. Anticipated date of completion: Spring 2025. Dissertation Title: *Friend or Foe: Elucidating the impact of previously defined pathogens on freshwater and marine fish microbiomes.*

Elizabeth Silvy. Texas A&M University, Ph.D. Student. Degree completed January 2020 (stayed on in technician position for additional 8 months to assist with project). Assisted in design, constriction, and operation of live foods harvesting system and larval fish management.

Adrián López-Porras. Mississippi State University, M.S. Student. Graduated: 2020. Thesis title: *Intraspecific variability of Edwardsiella piscicida and cross-protective efficacy of a live-attenuated Edwardsiella ictaluri vaccine in channel and channel × blue hybrid catfish.*

Debarshi Bhattacharjee. Texas Tech University, M.S. Student. Anticipated date of graduation: May 2022. Dissertation title: *Market trends and consumer demand for Southern aquaculture products of USA: An analysis of seafood scanner data.*

Grayson Clark. Texas A&M University, M.S. Student. Graduated: 2020. *Thesis title: Evaluating the effect of prebiotics and probiotics on rotifer and juvenile red drum (Sciaenops ocellatus) production*.

Bryan Candelaria. Texas A&M University, M.S. Student, Graduated: 2021. Thesis title: *Evaluating the effects of fermented and non-fermented cottonseed flour on growth performance of juvenile red drum and hybrid striped bass. M.S. Thesis, 49 pp.*

Alex Geddie. North Carolina State University, Graduate Student. Assisted in feeding and routine larval system management.

Mason Hancock. North Carolina State University, Graduate Student. Assisted culturing live feeds and routine larval system management.

Davida Johnson. University of California-Davis, School of Veterinary Medicine, Graduate Student.

Garrett Stamport. Texas A&M University, B.S. Degree. Completed: Dec. 2022. Assisted in feeding and operation of live foods harvesting system and larval fish management.

Allison Wise. Texas Lutheran University. B.S. Degree. Completed: Spring 2021.

James Hitchcock. Mississippi State University, Undergraduate Student.

Christopher Alford. Delta State University, Undergraduate Student.

Navtharika Thakur. Georgia Tech University, Undergraduate Student.

Appendix 1. List of Completed SRAC Projects to Date

Evaluation of Protein and Lipid Concentrations in Commercially Available Tilapia Feeds and Their Effect in Intensive Production Systems
Duration: 2017-2021 Funding Level: $184,844
Participants: TAMU, VT, BROCK FARMS, ASTOR FARMS

Policy Analysis of the Implications of Changes in Federal Authority Under the Lacey Act to Prohibit Interstate Movement of Injurious Wildlife
Duration: 2019-2021 Funding Level: $110,283
Participants: LSU, UF, UT, VT

Predation Risk and Economic Impact of Lesser Scaup and Piscivorous Waterbirds on Commercial Baitfish and Catfish Production
Duration: 2016-2018 Funding Level: $286,780
Participants: UAPB, MSU, USDA/WS/NWRC, VPI

Commercial Production of Selected Native Freshwater Ornamental Species
Duration: 2017-2019 Funding Level: $148,890
Participants: UF, LSU, VPI

Repeatability of Incidence and Time of Ovulation, Fecundity and Fertility in Channel Catfish Females Induced to Ovulate for Production of Hybrid Catfish Fry
Duration: 2017-2019 Funding Level: $126,619
Participants: AU, USDA/ARS/WARU, MSU

Techniques to Improve Production of Off-bottom Cultured Oysters
Duration: 2017-2019 Funding Level: $168,576
Participants: SCSGC, UG, UF, LSU, AU, NCSU

Field-Testing of a Rapid LAMP Assay to Detect the Marine Parasite *Amyloodinium ocellatum* in Commercial Aquaculture Facilities
Duration: 2017-2018 Funding Level: $92,018
Participants: AU, UF, USM

Improved Reproduction in Foodfish (Catfish and Largemouth Bass), Baitfish and Ornamentals Using a New Spawning Aid (GNRH IIA)
Duration: 2017- 2019 Funding Level: $192,287
Participants: AU, USDA ARS WARU

Evaluation of Probiotic and Prebiotic Supplements with Catfish, Golden Shiners, Hybrid Striped Bass and Tilapia under Conditions of Commercial Production
Duration: 2015-2017 Funding Level: $274,308
Participants: TAMU, AU, USDA ARS WARU, UAPB, ESA

Improvement of Blue Catfish Germplasm for Hybrid Catfish Production
Duration: 2014-2017 Funding Level: $44,343
Participants: USDA ARS WARU, LSU

Integrated Approaches to Reducing Individual Variability and Providing Year Round Harvest of Channel-Blue Hybrid Catfish
Duration: 2015-2017 Funding Level: $275,232
Participants: AU, USDA ARS WARU

Performance Evaluation of Intensive, Pond-Based Culture Systems for Catfish Production
Duration: 2012-2016 Funding Level: $292,891
Participants: USDA ARS WARU, AU, MSU, UAPB

Split-Pond Aquaculture Systems: Design Refinements for Catfish Production and Evaluation for Culturing Other Species
Duration: 2014-2017 Funding Level: $452,824
Participants: USDA ARS WARU, MSU, AU, USDA ARS NPURU, UAPB

Studies to Improve the Control of Virulent *Aeromonas hydrophila* and Evaluate the Impact of Environmental Factors on its Abundance in Catfish Aquaculture Ponds
Duration: 2014-2016 Funding Level: $354,287
Participants: AU, MSU, USDA NWRC

Using National Retail Databases to Determine Market Trends for Southern Aquaculture Products
Duration: 2009-2015 Funding Level: $397,845
Participants: UAPB, TTU, AU, UF

Improving Catfish Broodstock Management by Manipulating Diet, Stocking Densities, and Sex Ratios
Duration: 2011-2015 Funding Level: $382,463
Participants: UAPB, TAMU, USDA ARS WARU

Identification and Removal of Adhesive Proteins from Goldfish and Baitfish Eggs and Egg Masses
Duration: 2014-2015 Funding Level: $32,432
Participants: LSU, UAPB, UF

Implementation of Collective Action Alternatives Identified for the U.S. Catfish Industry
Duration: 2014-2015 Funding Level: $121,120
Participants: UAPB, AU, UCD, UMo

Effects of Mosquito Abatement Pesticides on Various Life Stages of Commercially Important Shellfish Aquaculture Species in the South
Duration: 2011-2012 Funding Level: $39,973
Participants: Coll. of Charleston, Sanibel-Captiva Conservation Foundation Marine Laboratory

Development of Baitfish, Goldfish and Ornamental Fish Hatchery Methods
Duration: 2011-2012 Funding Level: $59,957
Participants: UAPB, LSU, UF

Reproduction and Larval Rearing of Freshwater Ornamental and Marine Bait Fish
Duration 2011-2014 Funding Level: $499,400
Participants: UF, LSU, MSU

Potential Marketing Structures for the Catfish Industry
Duration: 2011-2013 Funding Level: $244,591
Participants: UAPB, AU, KSU, UCDavis, UMo

Evaluation of Impacts of Potential "Cap and Trade" Carbon Emission Policies on Catfish, Baitfish, and Crawfish Farming
Duration: 2011-2013 Funding Level: $119,952
Participants: AU, UAPB, LSU

Development and Evaluation of Cool-Water Crawfish Baits
Duration: 2011-2014 Funding Level: $124,326
Participants: LSU, TAMU, AU

Identifying Determinants for Development of Live-Market Grading Standards for Crawfish
Duration: 2011-2012 Funding Level: $49,952
Participants: LSU, UAPB

Improving Reproductive Efficiency of Cultured Finfish
Duration: 2009-2011 Funding Level: $493,973
Participants: USDA/ARS/CGRU, TAMU-CC, TAMU, AU, UF, UT, UAPB, USDA ARS NRAC

Economic Forecasting and Policy Analysis Models for Catfish and Trout
Duration: 2007-2009 Funding Level: $148,335
Participants: UAPB, LSU, MSU, NCSU, UF, AU

Improving Reproductive Efficiency to Produce Channel x Blue Hybrid Catfish Fry
Duration: 2004-2008 Funding Level: $460,000
Participants: AU, LSU, MSU, UMem, USDA/ARS CGRU

Development and Evaluation of Pond Inventory Methods
Duration: 2007-2009 Funding Level: $294,976
Participants: UAPB, LSU, MSU, UF, UMiss

Feed Formulation and Feeding Strategies for Bait and Ornamental Fish
Duration: 2005-2008 Funding Level: $335, 063
Participants: UAPB, TAMU, UF, UG

Innovative Technologies for Commercial-Scale Aquaculture
Duration: 2004-2008 Funding Level: $935,726
Participants: AU, CU, LSU, MSU, UAPB, USDA ARS CGRU, USDA ARS NARC

Identification, Characterization, and Evaluation of Mechanisms for Control of Bolbophorus Trematodes and Columnaris-Like Bacteria Causing Disease in Warm Water Fish
Duration: 2003-2006 Funding Level: $598,947
Participants: USDA APHIS WS, USDA-ARS SNARC, AU, CU, LSU, MSU, NCSU, UAPB, UT

National Aquaculture Extension Conference
Duration: 2002 Funding Level: $4,500
Participants: University of Arizona

Development of Improved Harvesting, Grading and Transport Technology for Finfish Aquaculture
Duration: 2001-2003 Funding Level: $750,000
Participants: UMem, MSU, NCSU, UAPB, UF, UT

Control of Blue-green Algae in Aquaculture Ponds
Duration: 1999-2001 Funding Level: $836,247
Participants: AU, CU, LSU, MSU, NCSU, UAPB, UG, UMiss, UT

Management of Aquacultural Effluents from Ponds
Duration: 1999-2002 Funding Level: $555,353
Participants: AU, LSU, MSU, NCSU, UAPB, Waddell MC

National Aquaculture Extension Conference
Duration: 1997 Funding Level: $3,700
Participants: Univ. of Maryland

Verification of Recommended Management Practices for Major Aquatic Species
Duration: 1997-2000 Funding Level: $160,305
Participants: AU, LSU, NCSU, UAPB

Optimizing Nutrient Utilization through Diet Composition and Feeding Strategies
Duration: 1996-1999 Funding Level: $732,804
Participants: AU, LSU, UMem, MSU, NCSU, LSU, TAMU, UAPB, UG

Management of Environmentally-Derived Off-Flavors in Warmwater Fish Ponds
Duration: 1996-1999 Funding Level: $866,281
Participants: AU, LSU, LaTech, UMem, MSU, TAMU, UAPB, UMiss, UT

Publications, Videos and Computer Software (Years 1-12)
Duration: 1995-2008 Funding Level: $826,000
Participants: TAMU

Improving Production Efficiency of Warmwater Aquaculture Species through Nutrition
Duration: 1994-1996 Funding Level: $760,466
Participants: AU, ECU, KSU, LSU, UMem, MSU, TAMU, UAPB, UG

Delineation and Evaluation of Catfish and Baitfish Pond Culture Practices
Duration: 1994-1997 Funding Level: $332,993
Participants: AU, LSU, MSU, TAMU, UAPB, UG

Aquaculture Food Safety: Residues
Duration: 1992-1995 Funding Level: $351,929
Participants: AU, LSU, MSU, TAMU, TennTech, UF, UG

National Coordination for Aquaculture Investigational New Animal Drug (INAD) Applications
Duration: 1992 Funding Level: $2,000
Participants: North Central Regional Aquaculture Center

National Extension Aquaculture Workshop
Duration: 1991 Funding Level: $3,005
Participants: UAPB, ACES, TAMU

Educational Materials for Aquaculturists and Consumers
Duration: 1991-1992 Funding Level: $133,142
Participants: AU, KSU, LSU, MSU, NCSU, OSU, TAMU, UF, UG, UVI

Characterization of Finfish and Shellfish Aquacultural Effluents
Duration: 1991-1994 Funding Level: $442,041
Participants: AU, CU, LSU, MSU, NCSU, TAMU, UAPB, UF, UG, VSU, Waddell MC

Food Safety and Sanitation for Aquacultural Products: Microbial
Duration: 1991-1995 Funding Level: $535,338
Participants: UT, AU, LSU, UF, UG

Preparation of Extension Publications on Avian Predator Control in Aquaculture Facilities
Duration: 1990-1992 Funding Level: $15,000
Participants: TAMU, MSU, UG, USDA APHIS ADC (MS, AR, LA, and S&T Field Station)

Effect of Nutrition on Body Composition and Subsequent Storage Quality of Farm-Raised Catfish
Duration: 1990-1992 Funding Level: $822,843
Participants: AU, KSU, LSU, MSU, TAMU, UG

Harvesting, Loading, and Grading Systems for Cultured Freshwater Finfishes and Crustaceans
Duration: 1990-1993 Funding Level: $373,952
Participants: LSU, AU, CU, UMem, MSU, UG, USL

Immunization of Channel Catfish
Duration: 1990-1991 Funding Level: $99,789
Participants: AU, LSU, UG

Enhancement of the Immune Response to *Edwardsiella ictaluri* in Channel Catfish
Duration: 1990-1991 Funding Level: $98,363
Participants: CU, TAMU, UG

Develop a Statistical Data Collection System for Farm-raised Catfish and Other Aquaculture Products in the Southern Region
Duration: 1989-1990 Funding Level: $13,771
Participants: MSU, LSU, AU, UA, TAMU, UG, LU, CU, UF, UT, VTU, USDA NASS

Performance of Aeration Systems for Channel Catfish, Crawfish, and Rainbow Trout Production
Duration: 1988-1990 Funding Level: $124,990
Participants: AU, LSU, MSU, NCSU, TAMU

Analysis of Regional and National Markets for Aquacultural Products Produced for Food in the Southern Region
Duration: 1988-1990 Funding Level: $346,038
Participants: AU, CU, LSU, MSU, TAMU

Preparation of Southern Regional Aquaculture Publications
Duration: 1988-1990 Funding Level: $150,000
Participants: AU, UA, UF, UG, KSU, LSU, MSU, NCSU, UPR, USC, TAMU, UVI