Southern Regional Aquaculture Center

TWENTY-SECOND ANNUAL PROGRESS REPORT

For the Period Through August 31, 2009

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

USDA United States Department of Agriculture
National Institute of Food and Agriculture

December, 2009

TWENTY-SECOND ANNUAL PROGRESS REPORT

SOUTHERN REGIONAL AQUACULTURE CENTER
Dr. Craig S. Tucker, Director
P.O. Box 197
Stoneville, Mississippi 38776
Phone: 662-686-3285
Fax: 662-686-3320
E-mail: srac@drec.msstate.edu
http://www.msstate.edu/dept/srac

TABLE OF CONTENTS

PREFACE

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. 95-113) 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.

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. 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]; and the Farm Security and Rural Investment Act of 2002 [P.L. 107-171]).

Projects that are developed and funded by the Regional Centers are based on industry needs and are designed to directly impact commercial aquaculture development in all states and territories. The Centers are organized to take advantage of the best aquaculture science expertise, education skills, and facilities in the United States. Center programs insure effective coordination and a region-wide, team approach to projects jointly conducted by research, extension, government, and industry personnel. Inter-agency collaboration and shared funding are strongly encouraged.

ACKNOWLEDGMENTS

The Southern Regional Aquaculture Center (SRAC) acknowledges the contributions of the Project Leaders and Participating Scientists involved in the projects reported in this Twenty-second 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 our Board, IAC and TC, and those serving as Administrative Advisors.

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.

INTRODUCTION

The Need for Aquaculture in the United States

Population growth, rising per capita incomes, and increased appreciation of the role of seafood in human health have caused global demand for seafood to triple since 1990. Meanwhile, foodfish output from capture fisheries was stagnant as stocks of ocean fish became fully exploited or, in many cases, over-exploited. The difference between the non-expanding supply from capture fisheries and rapidly expanding seafood demand was derived from aquaculture—the farming of aquatic plants and animals in oceans and inland waters.

Global aquaculture has grown at a phenomenal rate over the last 30 years to meet the expanding demand for seafood. Oddly, the United States, which is the third largest consumer of edible fisheries products in the world, lags behind many countries in aquaculture development, accounting for less than 2% of world aquaculture production. Aquaculture nevertheless plays a significant role in United States trade and agriculture, and there is considerable incentive for further development. Important in this regard, the United States is second only to Japan as the world's largest importer of edible fishery products, resulting in a significant international trade deficit. In 2008 the United States imported $14 billion of fish and shellfish products, with a trade deficit of almost $10 billion. This was the largest deficit item for any agricultural commodity.

United States seafood demand will continue to increase as a result of population growth and increased emphasis on eating seafood as part of a healthy diet. Although increased seafood demand provides considerable opportunity for growth of domestic aquaculture, production has been level since about 2000. Because significant economic and food security benefits accrue from producing fishery products rather than importing them, domestic aquaculture production must grow to meet the increasing demand for seafood by consumers.

Aquaculture in the Southeast

The farm-gate value of United States aquaculture exceeds $1 billion. The farm-raised catfish industry—centered in the three deep south states of Alabama, Arkansas and Mississippi—is the largest sector of domestic aquaculture, accounting for more than half of U.S. production. The southeast is also home to other large aquaculture sectors, such as farming of crawfish, hybrid striped bass, oysters, clams, and bait and ornamental fish.

Overall, about 70% of the $1 billion domestic aquaculture crop is produced in the southeast, and the regional economic impact goes far beyond the farm gate. Many of the support functions for the industry—such as feed manufacture and equipment fabrication—also take place in the region, and the total economic impact of aquaculture is many times the value of production alone. Further, if the overall economic value of aquaculture is viewed against a generally depressed agricultural economy, it is clear that aquaculture is a critical factor in the economy of the southeastern United States. However, the profitability of catfish farming and other aquaculture activities have declined to historic lows because of competition from imported products and higher production costs.

The Role of the Regional Aquaculture Centers

Technologies that improve production efficiency can help restore profitability to United States aquaculture and provide a reliable domestic source of seafood for the domestic consumers. Technology development is, however, costly, and support for research and development in aquaculture differs radically from that for traditional agricultural sectors such as poultry, cotton and soybeans. Farmers of those commodities rely on a vast infrastructure of private-sector agribusinesses to conduct most of the research needed to sustain industry growth. Aquaculture, on the other hand, receives little private-sector R&D support, relying instead almost entirely on public-sector funds for technology development.

Although government agencies, particularly the United States Department of Agriculture, 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, the Southern Regional Aquaculture Center has become the most important regional aquaculture activity in the southeastern United States. In its 22 years of operation, the Center has disbursed $15 million to fund multi-state research and extension projects. More than 200 scientists from 30 institutions in the southeast have participated in Center projects.

In the past year, SRAC funded six research projects totaling more than $2 million. The Center's "Publications" project is in its fourteenth year of funding and is under the editorial direction of faculty and staff at Texas A&M University. From this project, ten fact sheets and one PowerPoint presentation were completed this year with seven fact sheets, one power point presentation, and one project summary in progress. To date, the "Publications" project has generated 192 fact sheets and species profiles, 5 project summaries, 19 research publications and 20 videos with contributions from more than 190 authors from throughout the region.

Productivity from SRAC research projects has been excellent since the Center's inception more than two 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. For example, scientists in our project "Innovative Technologies and Methodologies for Commercial-scale Pond Aquaculture" have presented their results in 30 scientific papers and 50 presentations at meetings.

A more meaningful measure of the impact of SRAC projects is the extent to which results have been used by American farmers. An excellent example again comes from our project "Innovative Technologies and Methodologies for Commercial-scale Pond Aquaculture." As part of that project, economists at the University of Arkansas at Pine Bluff developed cash flow budgets for various farm sizes, management decisions, and financing options. The spreadsheet model budgets have been used extensively to provide direct financial assistance to catfish farmers through the recent difficult financial period. Several workshops on cash-flow management have been held to aid farmers to make decisions related to survival of their farm businesses, and farmers have reported that these models were helpful in decision-making through a difficult 2009 growing season.

Beginning with the first projects funded by the Southern Regional Aquaculture Center, 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.

This Twenty-second Annual Progress Report covers the activities of the Administrative Center during the past year. Progress reports on the six multi-year research and extension projects supported by SRAC during this reporting period cover the life of the projects from their initiation date through August 31, 2009.

ORGANIZATIONAL STRUCTURE

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.

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 all states within the region, works with the IAC to prioritize problem areas. The two groups then work together to develop "Problem Statements" describing objectives of work to solve problems with the highest priority. Using inputs from industry representatives, regional Work Groups of the most qualified research and extension scientists are formed. The Work Groups then plan and conduct the work in conjunction with an Administrative Advisor appointed by the Board. 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. Additional Administrative Center responsibilities are detailed in the "Administrative Activities" section of this report.

BOARD OF DIRECTORS

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

The structure of the Board is as follows:

Three members of the 1862 Southern Extension Service Directors Association
Three members of the 1862 Southern Experiment Station Directors Association
One member of the 1890 Association of Research Administrators
One member of the 1890 Association of Extension Administrators
One AHS administrator from the host institution

Members of the Board are:

Harold Benson, Kentucky State University
Gregory Bohach, Mississippi State University
Richard Guthrie, Auburn University
Wondi Mersi, Virginia State University
David Morrison, Louisiana State University
Gary Palmer, University of Kentucky Extension Service
James Rakocy, University of the Virgin Islands
Gaines Smith, Alabama Cooperative Extension System
Joe Street, Mississippi State University Extension Service

Ex-officio Board members are:

Chair, Industry Advisory Council
Vice-chair, Industry Advisory Council
Co-chair for Extension, Technical Committee
Co-chair for Research, Technical Committee
Director, SRAC

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) establishment of priorities for regional aquaculture research and extension education activities based on inputs from the TC and IAC and guidance from the National Aquaculture Development Plan; 4) review and approval of annual plans of work and accomplishment reports; and 5) final selection of proposals for funding by SRAC.

INDUSTRY ADVISORY COUNCIL

The IAC, which meets at least annually, 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 as deemed appropriate by the Board of Directors.

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 chairman serves for two years and is elected by IAC members.

Members of the IAC are:

Neal Anderson, AR
Lynn Blackwood, VA
Bill Cheek, LA
David Teichert-Coddington, AL
Jane Corbin, TN
Shorty Jones, MS
Bill Livingston, SC
Joey Lowery, AR
Bill Martin, VA
Robert Mayo, NC
Sandy Miller, GA
Steve Minvielle, LA
Rick Murdock, KY
Ben Pentecost, MS
Fernando Rodriquez, PR
Robert Schmid, TX
Dan Solano, FL
Marty Tanner, FL
Butch Wilson, AL

IAC members serve up to four-year appointments having staggered terms with options for reappointment.

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, progress reports, and termination reports; and 5) recommends to the Board, jointly with the TC, actions regarding new and continuing proposals, proposal modifications and terminations.

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 meets as needed, but at least annually, and has a co-chairman for research and a co-chairman for extension. Co-chairmen serve for two years and are elected by TC members.

Members of the TC for research are:

Brian Bosworth, MS
David Brune, SC
Jason Danaher, VI
Sid Dasgupta, KY
Allen Davis, AL
Patricia Duncan, GA
Carole Engle, AR
Delbert Gatlin, TX
John Kubaryk, PR
Tom Losordo, NC
Ray McClain, LA
Mike Oesterling, VA
Courtney Ohs, FL
Larry Wilson, TN

Members of the TC for Extension are:

Jimmy Avery, MS
Ron Blair, TN
Gary Burtle, GA
Jesse Chappell, AL
Dennis Delong, NC
David Heikes, AR
Greg Lutz, LA
Michael Masser, TX
Mike Schwarz, VA
Saul Wiscovich Teruel, PR
Craig Watson, FL
Jack Whetstone, SC
Forrest Wynne, KY

Technical Committee members serve up to four-year appointments having staggered terms with options for reappointment.

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

PROJECT CRITERIA

Projects developed within SRAC should meet the following criteria:

- Addresses a problem of fundamental importance to aquaculture in the Southern Region;
- Involves participation by two or more states in the Southern Region;
- Requires more scientific manpower, equipment, and facilities than generally available at one location;
- Approach is adaptable and particularly suitable for inter-institutional cooperation, resulting in better use of limited resources and a saving of funds;

- Will complement and enhance ongoing extension and research activities by participants, as well as offer potential for expanding these programs;
- Is likely to attract additional support for the work which is not likely to occur through other programs and mechanisms;
- Is sufficiently specific to promise significant accomplishments in a reasonable period of time (usually up to 3 years).

PROJECT DEVELOPMENT PROCEDURES

The IAC initiates the project development process by identifying critical problems facing aquaculture in the region. The TC and IAC then jointly prioritize problem areas and recommend the most important research and extension needs to the Board. Writing teams selected from the TC-IAC membership develop "problem statements" for each of the selected priority areas. Problem statements briefly describe the problem area and general objectives of the work to be conducted. The problem statement also includes a recommended funding level and project duration. Draft problem statements are then forwarded to the Board for approval to release project development funds.

Once an area of work has been approved, the Executive Committee (the SRAC Director, the co-chairs of the TC, and the chair and vice-chair of the IAC) appoints a Steering Committee to develop the "Call for Statements of Interest" and oversee development of the project proposal and the conduct of the regional project. The "Call for Statements of Interest" is distributed to state, territorial or federal institutions and private institutions within the Southern Region with demonstrated competence in aquaculture research and development. Interested parties respond by submitting a "Statement of Interest" to the SRAC Adminstrative Office. After careful review of the Statements of Interest, the Steering Committee recommends a Work Group consisting of selected project participants and the Steering Committee. The Work Group is responsible for preparing the regional project proposal and conducting work outlined in the proposal.

Project proposals are reviewed by the Steering Committee, IAC, TC, all project participants and designated peer reviewers from within the region and from outside the region. The SRAC Director submits the project proposal and peer reviews to the Board of Directors for review and approval. Proposals not approved by the Board are returned for revision or eliminated from consideration.

The Director prepares an annual plan of work, including all project proposals approved by the Board, and submits the plan to NIFA for approval. Pending a successful review of the project plan and budget, NIFA notifies SRAC of final approval. Letters of Agreement (subcontracts) between SRAC and participating institutions are then prepared and forwarded for approval and execution by the authorized institutional official. At that point, formal work on the project begins.

ADMINISTRATIVE ACTIVITIES

The SRAC administrative staff consists of the Center Director and Administrative Assistant. A wide variety of support functions for the various SRAC components, including the Board, TC, IAC, Steering Committees and project Work Groups are provided:

- Center Director serves as an ex-officio member of the Board, TC, and IAC.
- Monitor research and extension activities sponsored by SRAC.
- Solicit and receive nominations for memberships on the TC and IAC.
- Coordinate submission of written testimony to the U.S. House Agriculture, Rural Development, and Related Agencies Subcommittee on Appropriations regarding RAC support.
- The Director of SRAC serves as a member of the National Coordinating Council for Aquaculture which consists of the Directors of the five Regional Centers and appropriate USDA/NIFA National Program staff.
- Prepare and submit Grant Application to USDA/NIFA entering into funding agreement for each fiscal year, Annual Plan of Work and Amendments.
- Develop and execute appropriate Letters of Agreement with participating institutions in each funded proposal for the purpose of transferring funds and coordinating and implementing projects approved under each of the grants.
- Serve as fiscal agent to review and approve invoices and distribute funds to participating institutions as approved under the grants and as set forth in the Letters of Agreement.
- Prepare budgets for the Administrative Center, track administrative expenditures, and obtain USDA/NIFA approval for project and budget revisions.
- Prepare budget reports for the Board of Directors, tracking expenditures and status of funded projects and the Administrative Center.
- Assist Steering Committees and Work Groups with preparation and revision of proposals for technical and scientific merit, feasibility and applicability to priority problem areas.
- Solicit and coordinate national reviews of project proposals.
- Distribute fact sheets and videos to research and extension contacts throughout the Southern Region, other RACs, and USDA personnel.
- Produce and distribute the "SRAC Annual Progress Report," which includes editing and proofreading the project reports and producing camera-ready copy.
- Produce and maintain the web site for SRAC which provides downloadable copies of all SRAC fact sheets, the Operations Manual and Annual Reports, as well as lists of other research publications and extension contacts in the Southern Region.
- Prepare and distribute Calls for Statements of Interest to research and extension directors and other interested parties throughout the Southern Region.
- Respond to requests from aquaculture producers, the public, and research and extension personnel for copies of fact sheets, research publications and videos produced by SRAC and the other Centers, as well as requests for general aquaculture-related information.

PROGRESS REPORTS

The following cumulative reports detail the progress of research and extension work accomplished for the duration of the respective projects through August 31 of the current year. These reports are prepared by the Project Leaders in conjunction with the institutional Principal Investigators.

PUBLICATIONS, VIDEOS AND COMPUTER SOFTWARE

Reporting Period
March 1, 1995 - August 31, 2009

Funding Level

Year 1	$ 50,000
Year 2	60,948
Year 3	45,900
Year 4	60,500
Year 5	67,000
Year 6	77,358
Year 7	82,205
Year 8	77,384
Year 9	60,466
Year 10	50,896
Year 11	45,723
Year 12	71,288
Year 13	80,106
Year 14	79,913
Total	$909,686

Participants Texas A&M University System serves as Lead Institution, with Dr. Michael Masser as Project Leader. Participants in this project include authors and co-authors from all states in the region as shown in the listing of publications at the end of this report.

PROJECT OBJECTIVES

1. Review and revise, as necessary, all SRAC extension printed and video publications.

2. Establish an ongoing project location to develop and distribute new SRAC educational publications and videos for Southern Region aquaculture industries. This project will be responsible for preparation, peer review, editing, reproduction, and distribution of all Extension and popular-type publications for all SRAC projects.

3. Place current, revised, and new publications in electronic format (e.g., Internet or compact disk) for more efficient use, duplication, and distribution.

ANTICIPATED BENEFITS

The direct benefit from this project to the aquaculture industry is the widespread and ready availability of detailed information on production and marketing of aquacultural products. SRAC fact sheets, videos, and other publications are distributed worldwide to a diverse clientele.

Extension Specialists. 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 nationwide network of Extension Specialists and County Agents. This process assures an efficient publication process that makes use of the best available talent in specific subject areas. The result is widespread availability of high-quality educational material for scientists, educators, producers, and the general public.

Educators. Many high schools, colleges, and universities in the United States and around the world use SRAC technical fact sheets as reference material in aquaculture and fisheries courses. Educational institutions at the elementary and secondary level use SRAC extension materials in the classroom to make students aware of aquaculture production and associated trades as a possible vocation.

Consumers. Information is readily available for consumers who are seeking background information on aquaculture.

Producers. Information on the use of therapeutants, pesticides, methods of calculating treatment rates, and possible alternative crops and marketing strategies is in constant demand by aquaculturists. Videos that demonstrate such techniques are a ready source of "how-to" information.

Potential investors. Detailed information on production and marketing constraints and ways to alleviate or manage those constraints are particularly helpful to people making decisions about entering the aquaculture business. Economic information is used by lending agencies and potential investors, as well as established producers who use the information to help make day-to-day decisions on farm management.

Internet access. Availability of SRAC publications via the Internet and compact disk makes access faster and easier, facilitates searching for needed information, and reduces storage space requirements for printed documents.

Results at a glance...

- *More than 190 authors from across the United States have contributed to SRAC's publication projects.*
- *Ten fact sheets and one PowerPoint were completed this year with seven fact sheets, one power point presentation, and one project summary in progress.*
- *Sixteen scientists from across the Southern Region contributed to publications completed by SRAC this year.*
- *SRAC has now published 192 fact sheets and species profiles, 5 project summaries, 19 research publications, and 20 videos.*

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

During this current project year, four new fact sheets and six fact sheet revisions were completed and the Aquaplant web site updated. SRAC's first educational PowerPoint was developed. All publications have been distributed throughout the Southern Region and to interested Extension Specialists in other regions. Seven fact sheets are in some stage of writing, production, or revision. Two fact sheets have currently not had drafts submitted. One project summary is at printing and one has not been submitted. All SRAC publications are based on research conducted within the region or in surrounding areas.

Research funding from universities within the region, as well as funding from private sources, has been used to support the work on which the fact sheets are based. Copies of all SRAC fact sheets are available at <http://www.msstate.edu/dept/srac> and <http://srac.tamu.edu>.

Results at a glance...

Titles of some recent SRAC publications:

- *Algal Toxins in Pond Aquaculture*
- *Cage Culture: Harvesting and Economics*
- *Cage Culture Problems*
- *Crawfish Trap Design and Construction*
- *Hybrid Striped Bass: Hatchery Phase*
- *Hybrid Striped Bass: Pond Production of Food Fish*
- *Introduction to Non-Native Species in Aqauaculture*
- *Risk Analysis of Non-Native Species*
- *Small-Scale Marketing of Aquaculture Products*
- *Tank Culture of Tilapia*

WORK PLANNED

During the next project year, eleven new fact sheets/ species profiles, three PowerPoint programs, and one project summary will be produced. The new fact sheets will address: 1) pond effluent management, 2) chemical removal of fish, 3) facility biosecurity, 4) Amylodinium parasites, 5) mycotoxins in feeds, 6) principles of fish nutrition, 7) non-native species, 8) post-harvest handling of freshwater shrimp, 9) mycobacteriosis in fish, 10) biosecurity in recirculating systems, and 11) a species profile on black sea bass.

Three new PowerPoint presentations will be produced addressing: 1) largemouth bass culture, 2) viral hemorrhagic septicemia, and 3) aquaponics.

A final project summary from the project "Management of Aquaculture Effluents" will be developed (Yr 13).

IMPACTS

This is a highly productive project with significant regional, national, and international impact. Fact sheets and videos are regularly requested and used by clientele in all 50 states. Fact sheets generated within the Southern Region are also widely distributed by the other Regional Aquaculture Centers and

Results at a glance...

- *In the months from September 2008 through August 2009, more than 30,100 unique visitors came to the SRAC web site and accessed over 184,220 pages from the SRAC web site.*
- *All fact sheets completed by this project to date are available on the Internet at <http://www.msstate.edu/dept/srac> and <http://srac.tamu.edu>.*

extension personnel throughout the country. In addition to direct requests for printed material, fact sheets and other informational materials are accessed daily from the SRAC web site by people searching for technical information. In the period from September 2008 through August 2009, more than 30,100 unique visitors came to the SRAC web site and accessed over 184,220 pages. Since the fact sheets are also accessible through numerous other university research and extension web sites, the total usage and impact is undoubtedly several times greater.

Publications and videos produced by SRAC are increasingly used in educating high school and college students about aquaculture. In recent years there has been a rapid expansion of aquaculture curricula in high schools. These programs heavily utilize our publications and videos for educational purposes but usage is impossible to measure because many people access the information from Internet sites. Aquaculture and fisheries courses taught at many colleges and universities also use SRAC technical fact sheets as part of their course reference material. 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 indicates 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, although it has not been quantified. Consumers are primarily interested in a wholesome, safe, and inexpensive product, and it has been reported that the consumer-oriented 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 will be in increased demand by health conscious consumers.

PUBLICATIONS, MANUSCRIPTS OR PAPERS PRESENTED

Fact Sheets Completed (9/1/08 - 8/31/2009)

Hybrid Striped Bass: Hatchery Phase, SRAC 301 (revision), by Andrew S. McGinty and Ronald G. Hodson
Risk Analysis of Non-Native Species, SRAC 4303, by Jeffrey E. Hill
Introduction to Non-Native Species in Aquaculture, SRAC 4304, by Jeffrey E. Hill
Cage Culture: Harvesting and Economics, SRAC 165 (revision), by Peter Woods and Michael P. Masser.
Cage Culture Problems, SRAC 166 (revision), by Michael P. Masser and Peter Woods
Algal Toxins in Pond Aquaculture, SRAC 4605, John H. Rodgers, Jr.
Hybrid Striped Bass: Pond Production of Food Fish, SRAC 303 (revision), by Louis R. D'Abramo and Michael Frinsko

Small-Scale Marketing of Aquaculture Products, SRAC 350 (revision), by Siddhartha Dasgupta and Robert Durborow

Tank Culture of Tilapia, SRAC 282 (revision), by Dennis P. DeLong, Thomas M. Losordo and James E. Rakocy

Crawfish Trap Design and Construction, SRAC 2404, by Mark Shirley and C. Greg Lutz

Publications in press

Shipping Fish in Boxes, by Craig Watson, Kathy Heym Kilgore, and Carlos Martinez

Basic Aquaculture Genetics, by John Liu

Diseases of Concern in Molluscan Aquaculture, by Ryan B. Carnegie

Optimizing Nutrient Utilization and Reducing Waste through Diet Composition and Feeding Strategies, by Kenneth B. Davis

Manuscripts in review

Shellfish Handling Practices – Shrimp and Mulluscs, by Russell J. Miget

Biological Safety of Fresh and Processed Shellfish, by George J. Flick, Jr., and Linda A. Granata

Diagnosing Fish Kills, by Bill Hemstreet

Phytoplankton Culture, by LeRoy Cresswell

On-going project

Updating of the AQUAPLANT web site on aquatic weed management - M. Masser.

◆ ◆ ◆

INNOVATIVE TECHNOLOGIES AND METHODOLOGIES FOR COMMERCIAL-SCALE POND AQUACULTURE

Reporting Period
March 1, 2004 - August 31, 2009

Funding Level	Year 1	$314,409
	Year 2	$267,316
	Year 3	$204,857
	Year 4	$149,144
	Total	$935,726

Participants	Auburn University (Lead Institution)	Claude Boyd
	Clemson University	David Brune, T. E. Schwedler
	Louisiana State University	John Hargreaves, Robert Romaire
	Mississippi State University	Doug Minchew, Charles Mischke, Filip To
	University of Arkansas at Pine Bluff	Carole Engle, David Heikes
	USDA/ARS (Stuttgart)	Bart Green
	USDA/ARS (Stoneville)	Les Torrans

Administrative Advisor
Dr. Kenneth J. Roberts, Associate Vice Chancellor
LSU Ag Center
Baton Rouge, Louisiana

PROJECT OBJECTIVES

1. Evaluate new or improved production systems for channel catfish.

   a. Continuous production and inventory control with the partitioned aquaculture system.
   b. Installation of low-cost, semi-confinement systems in commercial-scale, earthen ponds.
   c. Fry and food fish production using in-pond raceways with the option for culturing supplemental species in open-pond areas.
   d. High-intensity production in heterotrophic-based culture units.

2. Improve equipment to enhance culture.

   a. Motor-powered U-tube aerator for commercial-scale channel catfish ponds.
   b. Low-head, low-speed paddlewheel aerator for crawfish ponds.
   c. Low-power, electrically-enhanced seine to harvest market-sized channel catfish from commercial-scale ponds.

3. Assess energy, material, and economic efficiency of production systems.

a. Quantify energy, protein, and water use in traditional systems for channel catfish culture.

b. Develop and evaluate economic and financial models of existing and improved production practices and technologies.

ANTICIPATED BENEFITS

Aquaculture operations in the southeastern United States find it increasingly difficult to maintain profitability as production costs increase and farm gate prices remain relatively low. Solutions to the problem are complex and multifaceted, but improved production efficiency can decrease production costs and improve the prospects for profitability. This project will provide new technology for production systems, aeration and harvesting techniques, and use of energy, materials, and capital. These technologies will be valuable in improving the profitability of aquaculture in the southeast.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Evaluate new or improved production systems for channel catfish.*

Objective 1a. *Continuous production and inventory control with the partitioned aquaculture system.*

Clemson University. The experimental trials in 2005 focused on 1) physical holding and handling of fry and fingerlings, 2) stocking density and required water flow rates, 3) feed presentation and food consumption, and 4) growth response under raceway culture conditions as opposed to an "accelerated" fingerling culture pond.

On 10 June 2005, channel catfish fry were stocked in six cells (1.83 m × 2.89 m × 1.22 m deep) located within the 0.81-ha PAS system (Figures 1, 2, and 3). Three cells were stocked with 5,000 fry and three cells with 10,000 fry. Fry were held in bins (46 cm × 76 cm × 30 cm deep) with 0.16-cm (1/16-inch) mesh screens for 1 week and then transferred to bins with 0.32-cm (1/8-inch) mesh screens for an additional week. After having reached an average size of 1.2 to 1.4 g, fingerlings were released into 0.63-cm (1/4-inch) mesh net-pens held within the 6.5-m^3 PAS cells. Each cell was supplied with water delivered by a 0.56-kW submerged aerator providing between 280 to 720 L/min to individual cells (Figures 2 and 3). After initial stocking, fish were fed starter feed of 52% to 56% protein supplied using automated feeders (Figure 4).

After 6 weeks, fingerlings had reached 11 to 14 g and hand feeding was initiated. At 7 weeks, fish in cells containing 10,000 fingerlings had reached 14 to 15 g, and were moved to grow-out raceways in the 0.1-ha PAS units (9.1 m × 2.1 m × 1.22 m deep). At the end of 8.5 weeks, fingerlings had reached 27 to 32 g in units stocked at 5,000 per cell, and 20 to 22 g in cells stocked at 10,000 per cell.

In addition to the fingerling culture trials conducted within cells and raceways, experiments were initiated to study the possibility of using PAS cells and raceways to provide a growth acceleration, or "boost" before stocking and grow-out in conventional fingerling ponds. A conventional, 0.20-ha fingerling culture pond was stocked with 34,000 fry (0.03 g/fish), while 17,000 fry of the same cohort were held in bins for 2 weeks with automated feeding until reaching 1.4 g. The "boosted" fry were stocked into a conventional, 0.12-ha fingerling culture pond. At

Figure 1. Overview of the 0.8-ha Clemson PAS unit with fingerling production cells.

Figure 2. Six, 4.5-m^2 fingerling production cell with aerator-driven water flow.

Figure 3. Individual fingerling production cell with aerator-driven water flow.

Figure 4. Automatic feeders used to feed fingerlings during initials stages of culture.

the end of culture trials fingerlings in both ponds were observed to be of similar size, reinforcing the importance of converting the boosted fry or fingerlings to floating feed as quickly as possible. Growth response in the "accelerated" pond was delayed as a result of slow initial response of the fish to hand feeding after being stocked in the pond.

On 10 October 2005, fingerlings in the cells, raceways and control ponds were harvested, sorted, counted and weighed (Table 1; Figure 5). After 120 days of culture, the net-pen cultured fingerlings grew from an initial weight of 0.10 g/fish (3- to 7-days-old) to an average harvest weight of 122 to 158 g (Figure 6). Feed uptake for the pooled net-pen fingerlings was fit to a power law (Figure 7) yielding the relationship:

Feed application rate (% body weight) = 0.3223 $X^{-0.551}$ where X = fish weight (g). The coefficient of determination (R^2) was 0.846.

Table 1. Average fingerling weight, density (in cells and ponds) and feed application rates in 2005.

Unit #	Size (g/fish)	Density (kg/m^3)	Loading/ feed(kg/ha)
Cell 1	122	112.9	2,576/63
Cell 2	139	136.7	2,576/63
Cell 3	124	111.3	2,576/63
Cell 4	158	47.7	2,576/63
Race 1	73	28.6	3,696/112
Race 2	77	28.6	9,072/215
Race 3	56	19.1	9,072/215
Pond 1	38	0.95	5,600/78
Pond 2	49	0.64	3,808/56

Figure 5. Fry stocking and fingerling harvest sizes.

On 1 June 2006, channel catfish fry were stocked into nine, 1.83 m × 2.89 m × 1.22 m deep cells located within the Clemson 0.8-ha PAS system. The experimental trials for 2006 focused on, 1) physical holding and handling of fry and fingerlings, 2) required water flow rates, 3) comparison of fingerling growth at base feed application rate (from 2005), +25% feed application, and at +50% feed application rate, 4) growth response under raceway culture conditions as compared to net-pen culture.

Figure 6. Final harvest fingerling size distribution in cell 2 (average wt = 139 gm) in 2005.

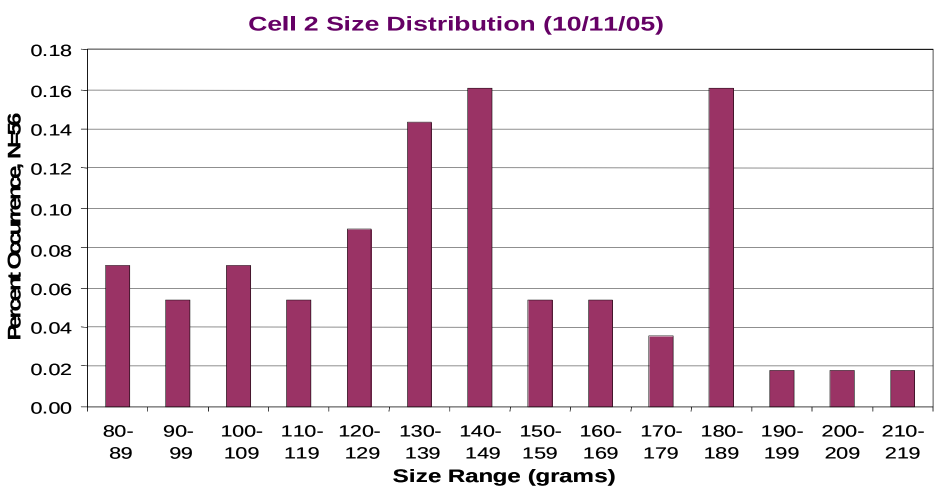
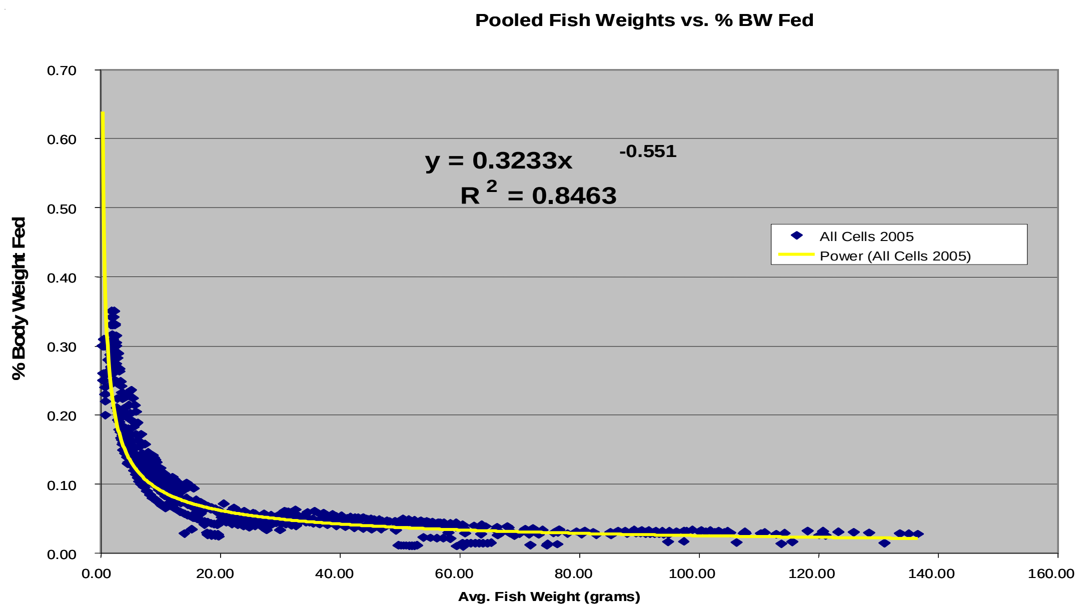


Figure 7. Observed, pooled fry/fingerling feed application rate vs fingerling wt. in 2005.



The nine, 6.5-m^3 cinder block cells were stocked with 3,000 fry in each cell (Figure 8). The fry were held in 1,050-cm^3 bins for 2 weeks, transferred to 3,710-cm^3 bins for two additional weeks, and after having reached 1.8 to 2.0 g in size, the fingerlings were released into a 0.63-cm (1/4-inch) mesh net-pens held within the cells. Each cell was supplied with water flow delivered from two 0.56-kW submerged aerators providing between 280 to 946 L/min flow to the individual cells. From the initial stocking, the fish were fed starter feed supplied with automatic feeders. After 8 weeks the fingerlings had reached 14 to 17 g in size. At 8 weeks, 14 to 15 g fingerlings were stocked into the 0.12-ha PAS raceways units (9.1 m × 2.1 m × 1.22 m deep) at a stocking rate of 74,130 fingerlings/ha.

Fish were harvested on 26 October 2006. End-of-season fingerling weight after 148 days of culture ranged from 126 to 133 gm/fish. Data suggested no statistical difference between fish harvest weight at base, +25, and +50% feed application rates. Overall food uptake rate and fish growth was pooled from the 2005 and 2006 fingerling culture trials and re-fit to a power law yielding the relationship:

Feed application rate (% body weight) = $0.2855X^{0.4818}$ where X = fish weight in grams.

Results at a glance...

- *The Clemson University Partitioned Aquaculture System (PAS) is particularly well-suited for production of channel catfish fingerlings. Growth is excellent, with fingerlings reaching approximately 140 g/fish (300 pounds/1000 fish) in 4 months. The semi-confinement units tested at the University of Arkansas at Pine Bluff also increased the yield of fingerling catfish in ponds.*

In 2006 culture trials, system-wide feed application rate to the two acre PAS peaked at a maximum of 118 kg feed/ha per day. Overall survival of fingerlings averaged 90%. In all cases observed fingerling growth was significantly reduced in raceways as compared to net-pen culture.

Beginning 15 June 2007, channel catfish fry were stocked into nine, 1.83 m × 2.89 m × 1.22 m deep cinder-block cells located within the Clemson 0.8-ha PAS system. At this time each of the nine cells were stocked with 5,000 fry. The fry were initially stocked (at 0.04 g) in the smallest bins with 0.16-cm (1/16-inch) mesh screens for 9 days of growth (reaching

Figure 8. High density PAS catfish fingerling culture in 6.5 m^3 (1720 gallon) cells with 63-cm (1/4-inch) mesh net cages.

0.32 g), after which time, they were transferred to larger bins with 0.32-cm (1/8-inch) mesh screens for an additional week until reaching 0.9 gm when they were transferred to 0.48-cm (3/16-inch) mesh bin where they were cultured until reaching an average size of 3.2 g (at 34 days), at which point, the fingerlings were released into 0.63-cm (1/4-inch) mesh net-pens held within the PAS cell. Each cell was supplied with water flow delivered with either 5-cm airlift pumps, or with 0.56-kW submerged aerators providing an initial flow-rate of 150 L/minute, with increased flow (at 5 g fingerling weight) of 1,250 liters per minute to the individual cells (Figure 7). At initial stocking the fish were fed starter feed of 52-56% protein, supplied with automated feeders. After 6 weeks of culture the individual fingerling weight averaged 7.3 to 8.6 g. The fingerlings were harvested after 143 days of culture at an overall combined average fingerling weight of 114 g/fingerling.

In the 2007 season, stocking rates and cell number were adjusted to target a system-wide fingerling carrying capacity approaching expected commercial production levels. Final maximum daily feed application rates exceeded 135 kg/ha of 40% protein feed with maximum fingerling carrying capacity of 4,200 kg/ha. Fingerling feed uptake rates were pooled from all three seasons (2005, 2006 and 2007) suggesting a final feed application relationship of:

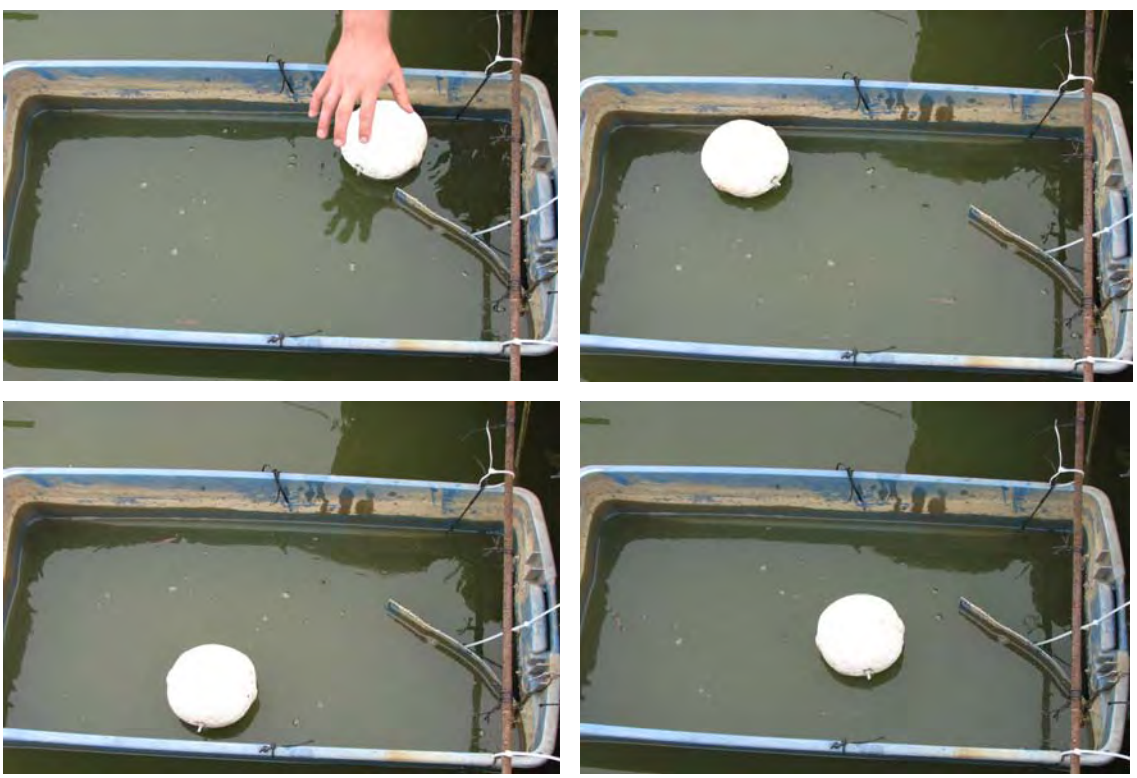
> Feed application rate (% body weight) = 0.3233X0.551 where X = fish weight in gms.

Results from the earlier 2005 and 2006 seasons suggested that fingerlings were extremely sensitive to variations in un-ionized ammonia concentrations resulting from water TAN concentration ranging between 1.0 to 2.0 mg/L at pH values ranging from 8.0-9.0. During 2007 trials, pH-values in four of the nine fingerling culture cells were continually suppressed 0.5 pH units with carbon dioxide supplemental to investigate the potential to increase fingerling feed uptake and growth through reduction in un-ionized ammonia concentrations. At the end of the season average fingerling sizes ranged from 96 to 126 g, and there was no statistically significant differences in fingerling growth attributable to pH adjustment.

In the 2008 season, three of the PAS fingerling growth cells were reconfigured to allow for passive water flow through the cell by utilizing the raceway-paddlewheel (Figure 9), in contrast to using airlifts or aerators to provide water flow as in the 2005, 2006 and 2007 seasons (Figure 8). The goal of these experimental trials was to investigate the possibility of using a lower cost system design, expected to be more economically viable for commercial application. The best configuration providing a controllable high flow rate through the cells consisted of combinations of baffles in the water delivery channel and "angled flaps" in the individual fry bins and fingerling net-pens directing water flow into a circular path within the fingerling cells and net pens (Figure 10). Maintaining a circular flow regime within the bins and net-pens was critical to keep feed from washing out at increased flow velocities. Fingerlings were placed into 0.16-cm (1/16-inch) mesh bins, 0.53 m × 0.46 m × 0.38 m at 5,000 fry/bin on June 2, 2008. On 13 June, fry were transferred to 0.32-cm (1/8-inch) mesh bins measuring 0.6 m × 0.53 m × 0.36 m. Finally on July 8 (36 days), fry were transferred to the 0.63-cm (1/4-inch) mesh net-pens, 2.74 m × 1.22 m × 0.91 m in size. Water velocities into bins and net pens ranged from 0.27 to 0.15 m/sec, yielding average water flow rates of 1,514 L/minute (400 gpm) in the bins (contrasted to 151 L/min using airlifts in 2007) and 7,570 L/min (2,000 gpm) in the net-pens (contrasted to 1,362 L/min using aerators in 2007). Bin and net-pen hydraulic detention times were reduced to 0.85 - 0.4 minutes using passive flow in 2008 as opposed to "pumped-flow" detention times of 2 to 5 minutes in the 2006/2007 growth trials. Water flow generated using airlifts and paddlewheels during the 2007 growing season for the entire 2-acre PAS system was 152% of the 2008 growing season. However,

Figure 9. 2008 PAS fingerling-cell configuration with paddle-wheel driven flow.

Figure 10. Demonstration of flap use to direct water flow into circular pattern in 2008 fry-bin providing capture zone for fine mesh fry-feed (0 sec, 2 sec, 8 sec, and 10 sec).



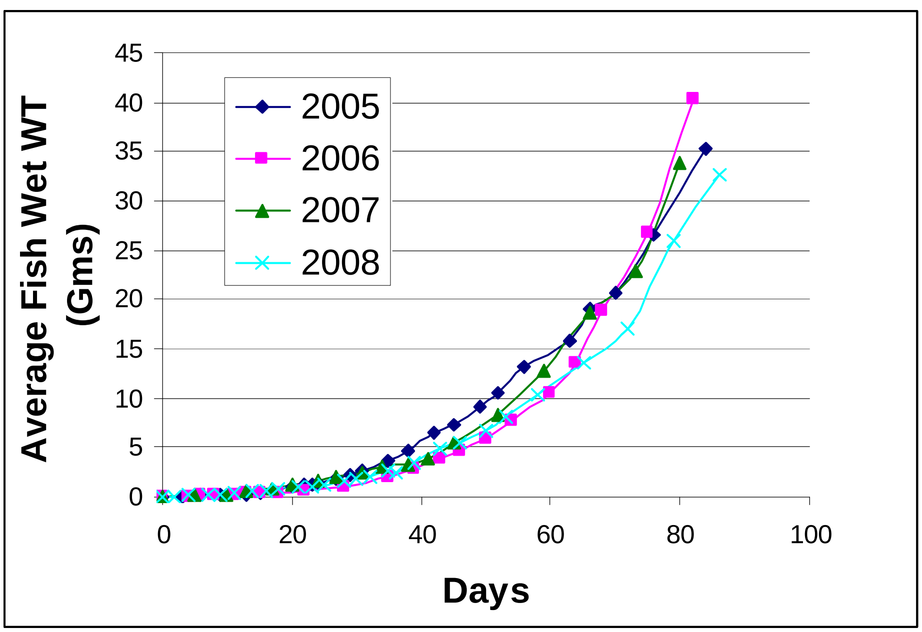
power requirements in 2008 were reduced by 58% by operating the system using passive flow rather than active flow.

The 2008 fingerlings were harvested after 65 days of growth. Growth to that point was compared to the previous three growing seasons (Figure 11) and was within one standard deviation of the average fingerling weight 65 days into the growing season. The 2008 growth rate follows the same trend over as earlier years using "active flow" water distribution. Water quality in the 2008 passive flow configuration was also similar to that in the active flow configuration used in previous years. Average dissolved oxygen concentration within the fish cohorts for the first 65 days during the 2005-2007 growing season was 5.3 mg/L with an average decrease in oxygen concentrations ("delta DO") within fish-holding units of 0.64 mg/L; average dissolved oxygen concentration for 2008 growing season was 4.5 mg/L with a "delta DO" of 0.25 mg/L. Average total ammonia-nitrogen concentration within the fish cohorts for the first 65 days during the 2005-2007 growing season was 0.50 mg/L with an increase in total ammonia-nitrogen concentration

Results at a glance...

- *In 2008 catfish fingerlings were grown at Clemson University in a "passive flow" PAS configuration. This modification reduced pumping energy use by 58% over previous "active flow" configurations. After two months of culture, fingerling weights (~30gms) were seen to be essentially the same as observed during earlier water distribution configurations.*

Figure 11. Comparison of average fry/fingerling size vs. time, from 2008 season using passive water flow distribution, as opposed to, previous years 1-3 using active water flow distribution.



("delta TAN") within a fish-holding unit of 0.38 mg/L; in 2008, the average TAN concentration was 1.08 mg/L, with a "delta TAN" of 0.02 mg/L.

Based on 4 years of growth data, the annual yield from a conventional fry/fingerling and foodfish production system was compared to 1) conventional fry/fingerling production followed by PAS grow-out and 2) PAS fry/fingerling production followed by PAS grow-out system. For this analysis we assumed a market channel catfish average weight of 1.63 pounds. For the conventional fry/fingerling ponds a carrying capacity of 2,100 pounds/acre was chosen, yielding an average 30-g fingerlings. Conventional foodfish production pond carrying capacity was projected at 5,000 pounds/acre. It was assumed that 70% of the stocked fingerling would be harvested after the first growing season and 30% would be carried over into a second growing season. The fingerling PAS carrying capacity was projected at 4,695 pounds/acre yielding an average 115-g fingerlings. PAS foodfish production carrying capacity of 18,000 pounds/acre was assumed. If stocked with conventional 30-g fingerlings, it is assumed that 70% of the stocked fingerlings would be harvested after the first growing season and 30% would be carried over into the second growing season. On the other hand if the system is stocked with 115-g fingerlings from the fry/fingerling PAS production, then 100% of the stocked fingerlings could be harvested in one growing season.

Projected yields showed that conventional fingerling production followed by foodfish growout in the PAS would produce a 300% increase in net fish yield per acre as compared to conventional pond fish production. The combination of fingerling PAS production followed by grow-out of foodfish in the PAS resulted in an additional 10% increase in annual harvest compared to conventionally grown fingerlings followed by PAS foodfish grow-out. The potential overall production increase from using fingerling PAS production is somewhat reduced by the large increase in PAS foodfish production compared to conventional pond foodfish production. Further, the much greater size "fingerling" produced in the PAS requires relatively a larger PAS area to produce a given number of fingerlings, which partially offsets the higher PAS fingerling carrying capacity. Nevertheless, fingerling production in the PAS offers a number of advantages over conventional production, including

- Potential for staged harvests during the growing season due to stocking with larger fingerling resulting in increased annual harvest without increasing carrying capacity;
- More control of over fingerling predation, disease treatment/vaccination, and harvest/inventory control in a PAS fingerling production system;
- Elimination or reduction in over-wintering requirements for food-fish reducing potential PGD mortality;
- Higher overall fingerling survival rate; and
- Reduced or eliminated water discharge

Mississippi State University. The PAS as currently configured in the Clemson system consists of an extensive, shallow algal growth basin (representing about 95% of the total system water surface area), and an intensive fish-confinement area in which fish are held at about 20 to 40 times the density of traditional ponds. In this objective, a modified PAS system, called the split-pond, was constructed that confines fish at a lower density than the Clemson system. The split-pond was built with a lower proportion of the total system area in the algal growth basin (about 80% of the total area) and a higher percentage of area in the fish-holding area (fish will be held at only 5 times the density of traditional ponds). The overall concept is to take advantage of the fish confinement benefits of the PAS (facilitation of inventory, harvest, feeding, health management, and protection against predation) while avoiding the need for intensive system management. A parallel goal of this objective is to design and evaluate a PAS-type system that can be constructed by retrofitting existing earthen ponds, rather than requiring new construction. This is accomplished by simply dividing an existing earthen pond into two sections with an earthen levee and then connecting the two sections with water flow induced by a slow-turning, energy-efficient paddlewheel.

In year 2004, one system was constructed in an existing 0.324-ha earthen pond at the National Warmwater Aquaculture Center, Stoneville, Mississippi (Figure 12). A 2-m-high earthen levee was constructed to separate the pond into two sections: a 0.227-ha algal basin and 0.073-ha fish-confinement area. Two, 3-m concrete-block sluiceways were constructed at either end of the cross-levee. One sluiceway was equipped with a six-bladed, 3-m long paddlewheel to induce water flow out of the fish confinement area and into the algal basin. The paddlewheel is 2 m in diameter and was installed to provide minimal clearance (less than 3 cm) with the sluiceway bottom and side walls. The paddlewheel can be operated at 1 to 6 rpm via a variable-speed, 3.7-kW hydraulic motor. The other sluiceway accommodates return flow from the algal basins into the fish confinement area. Both sluiceways were fitted with double barriers of 2.54-cm expanded metal to prevent fish escape out of the confinement area. Aeration in the fish confinement area is provided by eight, highly efficient deep-water release membrane diffusers. Air to the diffuser array will be provided by a 3.7-kW blower through a manifold of PVC pipe. The aeration system is designed to provide a field oxygen transfer rate of approximately 4.5 kg oxygen/hour at a water temperature of 30°C and 2 mg/L ambient dissolved oxygen. That rate should be adequate to meet the respiratory needs of at least 8,000 kg of fish.

Figure 12. The split-pond system at Stoneville, Mississippi. An existing 0.32-ha earthen pond was split into a waste-treatment basin (foreground) and a fish-holding section (barely visible over the dividing levee). The two basins are hydrologically connected by a low-speed paddlewheel (at the right) and a return-flow sluiceway (at the left).

The system was stocked with approximately 4,000 kg of catfish to optimize operating parameters. A paddlewheel speed of 1 rpm resulted in a water flow of 15.2 m3/minute through the fish-confinement basin. This flow rate was adequate to prevent accumulation of waste ammonia in the fish-confinement area at fish feeding rates of 150 kg/ha per day. At fish feeding rates of 175 to 200 kg/ha per day, total ammonia concentrations did not exceed 0.5 mg/L and dissolved oxygen concentrations remained above 3 mg/L.

In spring 2005, the system was stocked with 7,400 stocker-sized hybrid channel × blue catfish (24,710 fish/ha). Fish grew from an initial average weight of 0.08 kg/fish to an average of 0.78 kg/fish in a 6-month growing season. Total harvest weight was 5681 kg (18,940 kg/ha), for a net fish production of 5089 kg (16,960 kg/ha). Fish survival was 99% at a feed conversion efficiency of 1.87 kg of feed/kg of fish produced.

In spring 2006, the system was stocked with 11,100 hybrid channel × blue catfish (37,065 fish/ha at an average weight of 50 g/fish). As of August 23, 2006 fish averaged 0.43 kg/fish, giving a standing crop of approximately 16,000 kg/ha. In early September, a mechanical problem with the aeration system resulted in an acute nighttime dissolved oxygen depletion in the system and about half the fish standing crop was lost. The system was restocked with an equal number and weight of channel catfish to continue growout.

In spring 2007, the system was stocked with 9500 stocker-sized hybrid channel × blue catfish (29,320 fish/ha; average weight 80 g/fish). Fish were harvested in mid-November, 2007. Approximately 98% of the standing crop was harvested on the first seine haul. Total harvest weight was 7,275 kg (22,742 kg/ha) for a net fish production of 6,253 kg (19,479 kg/ha). Average fish weight at harvest was 0.91 kg/fish. Significant fish loss to *Edwardsiella tarda* infections in the last three weeks of growout reduced fish survival to 85% and feed conversion to 1.99. If those late-season losses are added to the final production (that is, if fish had been harvested 3 weeks earlier), net production would have been approximately 23,000 kg/ha with a feed conversion ratio of approximately 1.7. Maximum daily feeding rates averaged approximately 300 kg/ha in August and early September, yet total ammonia-nitrogen rarely exceeded 1.5 mg/L.

Results at a glance...

- *The Mississippi State University split-pond modification of the PAS can be constructed by modifying existing earthen fish ponds. Net annual catfish production has ranged from 17,000 to almost 20,000 kg/ha (15,000 to 18,000 pounds/acre) at feed conversion ratios less than 2.0. After successful scale-up in 2009, several catfish farmers are building split-ponds for commercial use in 2010.*

The system was renovated in winter 2008 to repair eroded embankments. The re-built system in 2008 consisted of a 0.065-ha fish confinement area and a 0.219-ha waste-treatment area, providing a total system area of 0.283 ha. In spring 2008, the system was stocked with 8750 stocker-sized hybrid channel × blue catfish (30,887 fish/ha; average weight 88 g/fish). Fish were offered feed to satiation daily starting 9 April. Fish were harvested 30 October 2008. Total harvest weight was 6,933 kg (24,432 kg/ha) with an average weight of 0.82 kg/fish. Net production was 6,153 kg (21,686 kg/ha). Survival was 97% with an feed conversion ratio of 1.90. Once again, maximum daily feeding rates averaged more than 300 kg/ha for several weeks in August and early September, yet total ammonia-nitrogen rarely exceeded 1.5 mg/L.

In April 2009, the system was stocked with 8750 stocker-sized hybrid channel × blue catfish (30,887 fish/ha; average weight 50 g/fish). Fish were harvested in late October, 2009. Total harvest weight was 20,160 kg/ha; net fish production was 18,620 kg/ha. Average harvest weight was 0.70 kg/fish. Harvested yield and net fish production were somewhat less than in previous years because smaller-sized stockers were used and a prolonged period of unseasonably cool, rainy weather in late August and September caused poor feeding conditions. Maximum daily feeding rates during that period averaged less than 250 kg/ha, whereas feed additions often exceeded 300 kg/ha per day during the same period in previous years.

A commercial-sized split-pond was constructed in 2008 and put into production in 2009. The large split-pond consists of a 1.42-ha algal basin and 0.40-ha fish-confinement area. Overall design was similar to the pilot-scale system used in previous years. Two, 3.7-m-wide concrete-block sluiceways were constructed at either end of an earthen cross-levee. Both sluiceways were fitted with double, expanded metal fish barriers to prevent fish movement between the two basins. Water was pumped from the fish-confinement area into the algal basin with a six-bladed, 3.66-m long, 2-m diameter paddlewheel installed in one sluiceway; the other sluiceway accommodated return water into the fish-confinement area. The paddlewheel was driven at 2.5 rpm with a 3.7-kW gearmotor, which induced a water flow of 60 m^3/minute. Aeration in the fish confinement area was provided by two, 7.5-kW paddlewheel aerators. Aeration and water flow was controlled by a set of remote-sensing dissolved oxygen probes. Aeration with one paddlewheel aerator was initiated when dissolved oxygen concentration fell below 5 mg/L in the fish confinement area; the second aerator was activated when dissolved oxygen concentration fell below 3 mg/L. The large paddlewheel pumped water between the two sections only when dissolved oxygen concentration was above 5 mg/L in the algal basin.

The large split-pond was stocked in April 2009 with 45,000 stocker-sized hybrid channel × blue catfish (24,700 fish/ha; average weight 54 g/fish). Fish were fed on 202 days until harvest in late October, 2009. Overall survival was 98% and total harvest weight was 19,210 kg/ha, giving a net fish production of 17,880 kg/ha. Average fish weight at harvest was 0.80 kg/fish. A total of 32,800 kg/ha of feed was offered to fish, resulting in a feed conversion ratio of 1.83. Average daily feeding rate over entire feeding period was 162 kg/ha, with maximum daily feeding rates averaging approximately 250 kg/ha in late August through September.

In addition to good fish production and few water-quality problems, the Stoneville "split-pond" system offers advantages related to confining the fish into a smaller area than in traditional ponds. Fish in the confinement area are easier to feed and harvest. The smaller area is also easier to protect from bird predation. Although not yet required in our studies, the fish-confinement area can be isolated from the rest of the pond, making it easier and far less expensive to use certain disease therapeutants because only about 15 to 20 percent of the total pond water volume is treated These attributes, combined with fish production characteristics that exceed those achieved in traditional ponds, make the split pond an attractive alternative for commercial catfish culture.

Objective 1b. *Installation of low-cost, semi-confinement systems in commercial-scale, earthen ponds.*

University of Arkansas at Pine Bluff. Five confinement systems were installed in research ponds at the UAPB Aquaculture Research facility to determine whether physically separating fish by size group with a pond confinement system would result in improved yield, survival, feed conversion ratio, and growth compared to normal multiple-batch culture. This study consisted of ten, 0.1-ha ponds; five were control ponds and did not have barriers. The five treatment ponds had a 1.27-cm × 2.54-cm PVC-coated wire mesh barrier that partitioned off a third of the pond. In the treatment ponds, fingerling catfish were reared in the smaller portion of the pond and larger carryover fish were stocked in the remaining larger portion of the pond. The fish in the control ponds were allowed to co-mingle as in traditional multiple-batch culture. Ponds were seined every 2 months during the growing season and average weights were calculated to estimate growth. After harvest, survival and FCR were calculated. The facility was stocked on April 28, 2005 and the study terminated on October 18, 2005.

Mean net yield of the fingerlings, total feed fed (kg/ha), and mean daily feeding rate (kg/ha/d) were greater in the confinement system than in the control ponds (Table 2). However, there were no differences in net yield of carryover fish, overall feed conversion ratio, or survival of either size of fish in the confinement system as compared to the control ponds. There were no significant differences in total ammonia, un-ionized ammonia, nitrite, nitrate, total nitrogen, and total phosphorus concentrations. The confinement system appears to offer potential to increase yield of fingerling catfish because of greater feed consumption in the system when the barrier is used to separate size classes. A partial budget analysis with price sensitivities was completed for the first study of raising fish in the confinement system. When fingerlings were physically separated from larger, carryover fish, significantly greater yields of fingerling (stocker) fish were achieved. There were no significant differences in survival, feed conversion ratio, or growth. The partial budget analysis revealed a positive net change of $367/ha or $38,125 for a 104-ha catfish farm at a market price of $1.54/kg of additional stockers produced (Table 3).

Another study was initiated in the spring of 2006 to compare production of catfish within the barrier system to open pond culture. This will help determine if there are any potential culture advantages to confining catfish to one-third of the total pond area. Stocker-sized catfish (136 g) were stocked into the smaller section of the confinement ponds and in the open ponds at a rate of 11,115 fish/ha. Yields, feed conversion ratios, and daily growth of food fish were significantly lower in the confinement system than in the open ponds, but there were no differences in survival (Table 4). However, seining efficiency was significantly greater for the confinement system.

Table 2. Selected data of fingerling and carryover fish in control and confinement ponds. Values with the same letter in the row are not significantly different. All values are mean ± SD.

	Control	Confinement
Net Yield (kg/ha)		
Fingerlings	1,788 ± 448a	2,391 ± 158b
Carryover	4,882 ± 490a	4,712 ± 679a
Total Feed Fed (kg/ha)	11,095 ± 541a	12,189 ± 579b
Mean Daily Feeding Rate (kg/ha/d)	62 ± 3a	67 ± 3b
Feed Conversion Ratio	1.67 ± 0.2a	1.68 ± 0.1a

Table 3. Partial budget analysis for the confinement system on a 104-hectare catfish farm, Study 1.

Parameter	Description	Unit Cost($)	Quantity	Benefit/Cost ($)/Farm	Benefit/Cost ($)/ha
Additional costs					
Variable Costs					
	Feed	250/ton	107	26,750	257
	Interest	0.10	1	2,675	26
Fixed Costs					
	Depreciation	179,336	10 yrs	17,934	172
	Interest			11,253[a]	108
Reduced revenue[b]				0	0
Total additional costs and reduced revenue				58,612	563
Additional revenue					
	Stockers	1.54/kg	62,816	96,737	930
Reduced costs[c]				0	0
Total additional revenue and reduced costs				96,737	930
Net change in profit				38,125	367

[a] Average annual interest based on a loan amortized for 10 years at 10% interest.
[b] There are no reduced costs from adopting the barrier system.
[c] There is no reduced revenue since there is an increase in yield resulting from the confinement system.

Table 4. Yield, survival, growth, mean weight and percent of the population that is sub-marketable at harvest of stocker catfish stocked in the confinement system and in open control ponds, Study 2. Values with the same letter in the row are not significantly different. All values are ± SD.

Production parameter	Unit	Confinement	Open
Gross yield	kg/ha	6,783 ± 345a	8,315 ± 254b
Net yield	kg/ha	5,274 ± 345a	6,806 ± 254b
Survival	%	80 ± 0.05a	85 ± 0.02a
Growth	g/d	3.69 ± 0.3a	4.29 ± 0.2b
Mean weight at harvest	g	759± 62a	884 ± 34b
Sub-marketable	%	22 ± 8a	13± 5a

The partial budget analysis (Table 5) showed a change in revenue of -$2,186/ha (-$227,334 across a 104-ha farm) at a food fish market price of $1.54/kg. Single-batch grow out of catfish stockers, under the conditions of this study, was not economically feasible in spite of the improved seining efficiency. Additional research is needed to determine whether refinements to the system can achieve yields similar to those in open ponds.

To evaluate scale-up issues, a commercial size barrier system was constructed on a catfish production facility in Chicot County, Arkansas (Figure 13). The barrier system was constructed in a 6-ha earthen

Table 5. Partial budget analysis for the confinement system on a 104-hectare catfish farm, Study 2.

Parameter	Description	Unit Cost($)	Quantity	Benefit/Cost ($)/Farm	Benefit/Cost ($)/ha
Additional costs					
Variable Costs		0	0	0	0
Fixed Costs					
	Depreciation	179,336	10 yrs	17,934	172
	Interest			11,253[a]	108
Reduced revenue	Foodfish	1.54/kg	159,328 kg	245,365	2,359
Total additional costs and reduced revenue				274,552	2,640
Additional revenue[b]		0	0	0	0
Reduced costs					
	Feed	250/ton	171.7	42,925	413
Interest			0.1	4,293	41
Total additional revenue and reduced costs				47,218	454
Net change in profit				-227,334	-2,186

[a] Average annual interest based on a loan amortized for 10 years at 10% interest.
[b] There is no additional revenue from adopting the barrier system.

Figure 13. Construction of a commercial-scale confinement system in a 6-ha earthen pond in Chicot County, Arkansas.

pond that was under renovation. Construction of the barrier system was completed by mid-October 2006. The barrier system was stocked with channel catfish on 21 March 2007. Approximately 2 weeks after stocking, it was evident that catfish were escaping from the barrier system. Within a month, the number of catfish outside the barrier had increased to a critical level and the farm manager had to start feeding fish on both sides of the barrier. We found a 5- to 7-cm gap between the barrier and the pond bottom along a deep depression about mid-way across the pond where the fish were congregating. This area was the deepest part of the pond along the transect where the barrier was constructed. Due to the escapement problem, the barrier was removed from the pond and the study was terminated.

Several factors may be responsible for barrier failure, and these factors may seriously affect the usefulness of this practice. First, poor compaction of the soil during pond renovation resulted in low spots being filled with loose fill material. Second, the barrier was not buried deep enough to get at least 15 cm below the hard-pan bottom of the deepest section of the pond. After all the loose fill material was swept clean from this area by fish activity, the bottom of the fence was exposed. In smaller research ponds over two separate seasons of production we never had a fish escape. However, because the fencing material was only 1.8 m, we had to decrease the height of the standpipe and thus the pond depth to keep fish from going over the top. If we would have buried the commercial pond barrier deep enough to prevent this problem, we would have had to drop the level of the standpipe by at least 0.3 m.

An alternative confinement system was designed and constructed in two, 0.1-ha research ponds during the spring and early summer of 2008 to address the escapement issue and to take advantage of the benefits related to segregating fish by size. The current design (Figure 14) includes two, 18-cm

Figure 14. Overview of the circular production units constructed in a 0.25 acre pond at the University of Arkansas at Pine Bluff, Aquaculture Research Facility.

(7-inch) diameter confinement systems constructed of 1.8-m-high PVC-coated wire mesh fastened to steel fence posts and imbedded in a circular concrete slab. Each production unit (pen) was fitted with a sliding gate mechanism that provides for the attachment of a standard harvesting sock for fish movements. Also, each pen includes a simple feeding tube to direct blown feed to the pen, a feed containment ring, and protective bird netting. Standard paddlewheel aeration was positioned so that aerated water would circulate through both the pens (Figure 14). Construction of the pens was completed in mid-July, 2008.

Channel catfish (1,500 fish, 69 g/fish) were stocked into one pen in each pond on 21 July 2008. This corresponds to a fish density of approximately 350 fish/m3 (10 fish per cubic foot) and a stocking density of 13,400/ha of pond. These fish have responded well to the system and production data is currently being collected. The second pen in each pond was stocked with larger channel catfish (1,500 fish weighing 350 g/fish) on 21 August 2008. These fish have also responded well to the system. Production data will be collected through the remainder of the 2008 growing season.

Objective 1c. *Fry and food fish production using in-pond raceways with the option for culturing supplemental species in open-pond areas.*

Louisiana State University. As part of an effort to improve the efficiency of intensive pond aquaculture systems, the potential for double-cropping freshwater prawns in Louisiana was evaluated. Juvenile prawns were stocked into twelve, 400-m2 ponds at a nominal density of 2.5/m2 on 7 May and fed a 32%-protein sinking feed at a daily rate of 25 kg/ha. Vertical substrate at 25% of pond surface area was installed in each pond. Ponds were aerated nightly. Prawns in six ponds were harvested between 3-4 August (after 88-89 d) and subsequently re-stocked with prawn juveniles that were cultured until November 7-9 (91-93 d); prawns in six ponds were cultured from early May until early November (184-186 d). Prawns harvested in the single-crop treatment were 55 g each, whereas prawns harvested from the first (early) crop were 24 g each and the prawns from the second (late) crop were 29 g each. In aggregate, production from double-cropped ponds was 822 kg/ha and production from single-cropped ponds was 568 kg/ha. An economic evaluation of the two cropping systems is being conducted. More prawns were produced in the double-crop treatment, but the prawns were of lower average weight than the prawns produced in the single-crop treatment. The additional biomass in the single-crop treatment will be evaluated relative to the price premium that can be obtained for larger animals. Also during 2007, development of the Partitioned Aquaculture System (PAS) continued, including automation of data acquisition. In particular, development of a cost effective system to monitor and manage critical water quality parameters, including dissolved oxygen, pH, and nitrite nitrogen continued. Development of linkage between this project and a related project in which autonomous vehicles were used to capture water quality in ponds and natural water bodies is in progress.

A 0.3-ha (0.75-acre) Partitioned Aquaculture System, with three fish-culture raceways, were stocked with channel catfish, blue catfish, and channel × blue catfish hybrid fingerlings in separate raceways between 29 June and 19 July. Average stocking size and density were as follows: channel catfish, 29 g and 5,000 fish/raceway; channel × blue catfish hybrids, 32 g at 5,000 fish/raceway; and blue catfish, 36 g and 4,683 fish/raceway. The collective stocking density of catfish was 14,683 fish (48,300/ha). Catfish were fed daily, generally as much as they would consume. In July 1,396 Nile tilapia weighing 391 kg (average weight = 272 g) were stocked into the open pond area of the system for algal control. After 533 days of culture, catfish were harvested.

Production of blue catfish and channel × blue hybrids were 2.4 times higher than for channel catfish (Table 6). Total catfish production of 4,570 kg equated to a yield of 15,014 kg/ha. Recovery rates of channel catfish from the PAS were low compared to blue catfish and channel × blue hybrids. No disease-related mortality was observed although wading birds were able to predate on some catfish. Feed consumption and subsequent growth of blue catfish and channel × blue catfish hybrids were 2 to 3 times higher than channel catfish which verifies finding from other studies that blue catfish and channel × blue hybrids appear to be better suited for high density cultivation. Feed conversion ratio of the system as a whole was 1.59. The presence of tilapia as biological filter-feeders in the open area of the PAS stabilized oxygen concentrations, and odiferous species of blue-green algae were rarely observed in the PAS. All tilapia died from cold water temperatures in January indicating that probably Nile tilapia overwintering in south-central Louisiana is remote.

Table 6. Recovery, size, and yield of channel, blue, and channel × blue catfish hybrids in three raceways in a 0.75-acre (0.3 ha) partitioned aquaculture system (PAS), Aquaculture Research Station, LSU AgCenter, Baton Rouge, LA.

Species	Number Stocked	Number Recovered	% Recovered	Total Weight of Fish (kg)	Average Size after 533 days (g)
Channel Catfish	5,000	2,126	43	783	368
Blue Catfish	4,683	3,088	66	1,824	590
C × B Hybrids	5,000	3,482	70	1.963	563
Total	14,683	8,696	59	4,570	

Objective 1d. *High intensity production in heterotrophic-based culture units.*

Louisiana State University. The performance of a heterotropic-based "biofloc" system consisting of eight 1.5-m3 tank mesocosms stocked with tilapia (3.0 kg/m3, 41 g/fish) was investigated in an indoor wet laboratory. Vigorous diffused aeration was provided to maintain solids in suspension, provide oxygen, and remove carbon dioxide. Settleable solids concentration was measured daily in each tank and maintained at eight different nominal concentrations (5, 10, 15, 20, 25, 50, 75, 100 mL/L) through intermittent operation of 80-L settling columns and removal of solids. The range of settleable solids concentration was equivalent to a range of total suspended solids concentration of about 250 to 1,000 mg/L. Daily feeding rate was increased weekly by 25 g/m3 and water quality was measured weekly before feeding rate adjustments. The biofloc system operated effectively within arbitrarily established water quality limits for ammonia, nitrite, carbon dioxide, and dissolved oxygen concentrations across a broad range of solids concentration and feed loading. After 11 weeks and a daily feeding rate of 275 g/m3, total ammonia concentration exceeded the pre-established criterion of 2 mg N/L in all tanks. For these indoor tank mesocosms, the sustainable maximum daily feeding rate is about 200 g/m3. At daily feeding rates greater than 200 g/m3, control of solids concentration became more difficult and water quality became more variable. Process instability was related to the development of filamentous bacteria that produced severe foaming associated with flocs with poor settling characteristics. As solids concentration increased, water respiration rate, nitrification rate, and solids retention time increased, and hydraulic retention time decreased. Increases in water respiration and nitrification rates were also related to increases in daily feeding rate. There was no effect of solids concentration on specific growth rate (1.27 %/day), final biomass density (9.8 kg/m3), and feed conversion ratio (1.83). After a cumulative feed loading of about 12 kg/m3 and a cumulative feed burden of about 130 kg/m3, tilapia in all tanks displayed signs of respiratory distress and stopped feeding. All tilapia in one tank died. This loading limit was independent of solids concentration. Hypotheses offered to explain this effect include combined metal toxicity related to low hardness, nitrate toxicity, or some factor associated with the accumulation of dissolved organic matter. Within three days of a 50% dilution of tank volume, fish resumed feeding, indicating that dilution sufficiently reduced the concentration of the factor that caused cessation of feeding.

Based on the findings of 2006 biofloc study, the effect of cumulative feed burden (CFB) on the performance of a recirculating biofloc (a combination of suspended solids and attached microorganisms) tilapia system was investigated in eight 1.5-m3 indoor tanks stocked with tilapia (5.1 kg fish/m3, 183 g/fish) and cultured for 21 weeks. All tanks were vigorously aerated to provide oxygen (DO, 6.4-6.8 mg/L), homogeneous mixing of solids, and CO_2 stripping. Each tank was managed at one of eight CFBs. CFB is a measure of water use intensity and is calculated as the daily feeding rate (g/day) divided by daily effluent (water replacement) rate (L/day). Culture tanks were managed with a CFB of 1, 2.5, 5, 10, 15, 25, 50, or 100 g/L. CFB was managed by increasing the daily water exchange rate with the increase in daily feeding rate. The daily feeding rate was initially 85 g/m3, increased weekly by 15 g/m3, and ended at 325 g/m3. Water quality (TAN, NO_2-N, NO_3-N, TSS, pH, total alkalinity, CO2, water respiration, temperature and DO) was measured weekly. Settleable solids were controlled at concentrations less than 100 mL/L by intermittent operation of an 80-L settling column. Alkalinity was maintained near a targeted level of 150 mg/L as $CaCO_3$ by weekly additions of $NaHCO_3$.

The NO_2-N, pH, and alkalinity increased with a decrease in CFB, and NO_3-N, TSS, water respiration, and CO_2 decreased. Higher mean NO_2-N concentrations were observed in tanks with CFBs of 2.5 and 1. Nitrite concentration was negatively correlated with a decrease in TSS. The increased water exchange rate (i.e. shorter solids retention time, SRT), associated with low CFBs, likely resulted in a loss of nitrifying bacteria in the effluent that exceeded the ability of remaining nitrifying bacteria to process substrate inorganic nitrogen, thus resulting in significant accumulation of nitrite in tanks with a CFB of 2.5 and 1. Findings of this study indicated that a CFB of 5 or higher was needed to maintain satisfactory water quality conducive to fish production in biofloc recirculating systems.

United States Department of Agriculture-Stuttgart (formerly at Pine Bluff). An intensively-managed, microbial-based production system has been used successfully to culture penaeid shrimp and tilapia, and appears to have potential application in growing catfish. When used for penaeid shrimp or tilapia production, the microbial floc that develops in the culture unit serves as a sink for ammonia-nitrogen and as a supplemental food source for the culture species. While it is unlikely that catfish will derive nutritional benefit from the microbial floc, bacterial control of ammonia-nitrogen may permit increased catfish stocking and feeding rates.

Nine tanks (4.6 m × 9.2 m × 0.9-m water depth) with semi-circular ends that are equipped with a center divider and lined with HDPE were filled with well water on 6 April 2005 and each fertilized with

0.32 kg 18-46-0 fertilizer. Stock salt (5 kg/tank) was added on 12 April 2005 and 12 August 2005. Each tank was equipped with a 0.37-kW electric paddlewheel aerator that operated continuously. Well water was added periodically to replace evaporative losses.

In 2004, stocker channel catfish (un-vaccinated) stocked in the tanks suffered high mortality from ESC (Edwardsiella ictaluri). Channel × blue hybrid catfish were stocked in 2005 because they appear more resistant to ESC. Hybrid catfish (mean weight 0.085 kg/fish), obtained from the ARS Catfish Genetics Research Unit, Stoneville, Mississippi, were stocked on 13 April 2005 at 25, 50, 75, 100, 125, 150, 175, 200, or 225 fish/tank. A stocking error was detected for the 125-fish treatment, so that treatment was excluded. Fish were fed a 32% protein floating feed daily to apparent satiation. Beginning on 14 July 2005, white flour (0.7 kg/kg feed), as a flour-water slurry, was added daily as an additional source of carbon to tanks. Agricultural limestone (250 mesh) was added to tanks as needed beginning in mid-August to mitigate low water pH. All tanks were harvested by draining on 17 October 2005.

Hybrid catfish survival after 188 days ranged from 61.3 to 79.1%, with an average of 71.0% (Table 7). Mean individual weight at harvest appeared independent of stocking rate up to a stocking rate of 100 fish/tank (2.4 fish/m2), and decreased linearly (y = 0.0017x + 0.6988; R2 = 0.9835) at stocking rates of 100 to 225 fish/tank (2.4 to 5.5 fish/m2) (Table 7; Figure 15). Fish biomass at harvest increased linearly with stocking rate (Figure 16). Feed conversion was variable, ranging from 1.8 to 6.3, and averaged 2.8. Daily feed rates ranged from 13 to 331 kg/ha. The feeding response by hybrid catfish in the tanks was variable and appeared unpredictable.

Mean weekly nitrite-nitrogen concentrations were low and independent of fish stocking rate (or the total amount of feed fed; Table 8). Nitrite-nitrogen concentrations remained low throughout the experiment except between days 60-80 when concentrations spiked as high as 5.78 mg/L NO_2-N. Mean weekly nitrate-nitrogen concentrations were high and increased as fish stocking rate increased (Table 8). Concentrations of NO_3-N were 0.30 mg/L or less through about day 60, after which concentrations increased. Mean weekly total ammonia-nitrogen (NH_3-N) concentrations were

Table 7. Mean weight at harvest, gross and net yields, and survival of channel × blue hybrid catfish after 188 days. At stocking, mean fish weight was 0.085 kg/fish.

Fish/Raceway	Mean Weight (kg/fish)	Yield (kg/m^3) Gross	Net	Survival (%)
25	0.53	0.22	0.18	64.0
50	0.50	0.47	0.38	78.0
75	0.54	0.66	0.52	61.3
100	0.54	0.86	0.67	77.0
150	0.44	0.94	0.66	70.7
175	0.40	1.16	0.84	73.7
200	0.35	1.08	0.69	64.0
225	0.34	1.34	0.86	79.1

Figure 15. Mean individual weight at harvest of channel × blue hybrid catfish stocked at 25 to 225 fish in 41-m² raceways.

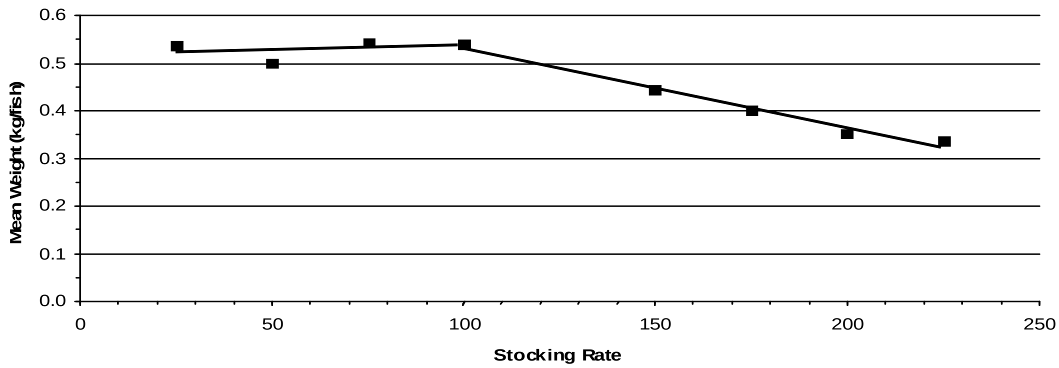
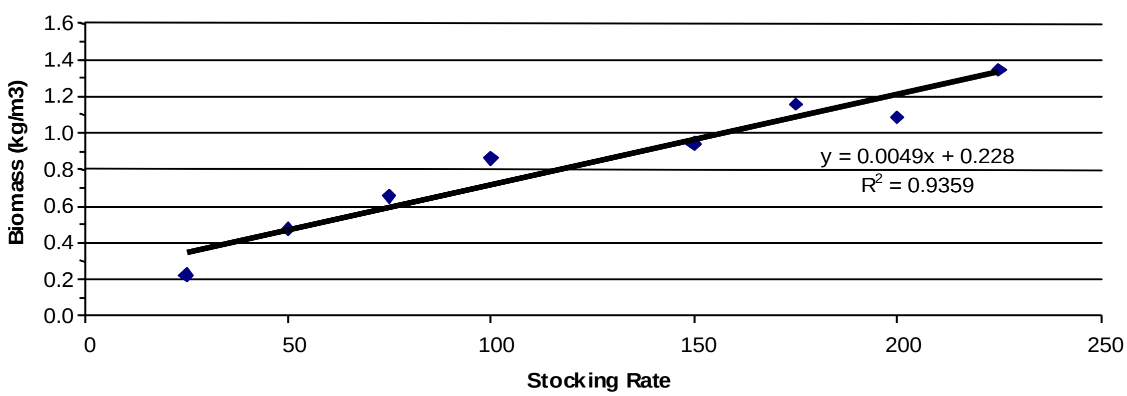


Figure 16. Relationship between final biomass and stocking rate of channel × blue hybrid catfish in 41-m² raceways.



low and independent of fish stocking rate (Table 8). There were several spikes in total NH_3-N concentration, generally in the tanks stocked with greater than 150 fish. The concentration spikes were short-lived and likely inconsequential to stocked fish because pH values were less than 7.9, and often less than 7.0. A maximum of about 5% of the total NH_3-N would be present as un-ionized ammonia at the water temperatures when the concentration spikes were observed. Mean weekly total nitrogen (N) and organic N concentrations were high and each increased linearly as fish stocking rate increased (R^2 = 0.855 and R^2 = 0.909, respectively; Table 8). Total N and organic N concentrations increased throughout the experiment. Organic N was, on average, 59% of the total N concentration.

Mean, weekly soluble reactive phosphorus was low and independent of fish stocking rate (or total amount of feed fed) below about 150 to 175 fish/

Table 8. Mean weekly concentrations of dissolved inorganic nitrogen and phosphorus, total nitrogen and phosphorus, organic nitrogen, pH, and chlorophyll *a* in raceways stocked with 25 to 225 channel × blue hybrid catfish.

Fish/ Raceway	NO_2-N	NO_3-N	NH_3-N	Total N	Organic N	PO_4-P	Total P	pH	Chlorophyll *a*
				mg/L					mg/m^3
25	0.390	13.88	0.03	30.91	16.60	0.26	1.07	7.30	1,241.6
50	0.056	7.19	0.29	22.57	15.03	0.16	0.93	7.50	908.1
75	0.197	9.66	0.01	25.77	15.90	0.08	0.74	7.29	1,264.4
100	0.108	12.31	0.01	32.08	19.65	0.24	1.03	7.28	803.2
150	0.225	16.83	0.02	43.13	26.06	0.27	1.38	7.07	1,223.8
175	0.289	18.75	0.03	45.23	26.15	0.15	1.11	7.01	1,126.8
200	0.106	21.60	0.35	53.08	31.04	0.57	1.50	6.74	1,461.0
225	0.205	28.82	0.38	67.43	38.02	0.76	2.00	6.64	1,454.5

raceway. Mean weekly concentrations increased linearly with increased fish stocking rate. Total phosphorus mean weekly concentrations ranged from 0.93 to 2.00 mg/L PO_4-P and increased linearly as stocking rate increased ($R^2 = 0.809$; Table 8).

Mean weekly early morning pH was 7.50 or less and decreased linearly as fish stocking rate increased ($R^2 = 0.869$; Table 8). During the first 100 days, mean, weekly early morning pH values were similar among tanks, and ranged from pH 7 to 8. After day 100, weekly early morning means became more variable and trended lower at stocking rates 150 fish/tank and greater. Afternoon pH generally was 0.5 to 1.0 pH units greater than the morning pH.

Mean, weekly chlorophyll *a* concentrations were high and increased linearly ($R^2 = 0.425$; Table 8). Chlorophyll *a* concentrations increased throughout the experiment in all tanks, attaining concentrations of 1,000 to 2,500 mg/m3 at the end of the experiment. A combined photoautotrophic-autotrophic bacteria system appeared to control tank water quality. Phytoplankton (photo-autrotrophic) removed dissolved inorganic nitrogen and inorganic carbon as alkalinity or carbon dioxide. Autotrophic bacteria involved in nitrification oxidize ammonia to nitrate in a two-step process mediated by bacteria of two distinct genera. The populations of nitrifying bacteria appear to have become established in two stages beginning with increasing populations of ammonia oxidizing bacteria around days 60 to 80 that produced a spike in nitrite-nitrogen concentrations. Populations of nitrite oxidizing bacteria lagged slightly, with concentrations of nitrate beginning to increase around day 80. Total ammonia-nitrogen remained low throughout the experiment.

Nitrification results in decreased pH values, which were more apparent in tanks with the higher stocking rates. Applications of agricultural limestone were necessary in all tanks to mitigate the decrease in pH.

The 2006-2007 trial continued to investigate the effect of stocking rate on production of catfish in heterotrophic-based tank units. Three stocking rates were selected based on the 2005-2006 results.

On 28 March 2006, tanks were stocked with stocker hybrid channel × blue hybrid catfish obtained from the ARS Catfish Genetics Research Unit, Stoneville, Mississippi. Stocking rate was 100, 300, or 500 fish/tank (2.6, 7.9, or 13.1 fish/m3). Treatments were assigned randomly to tanks. There were three replicates per treatment. At stocking, fish averaged 0.069 kg/fish. Fish were fed daily to apparent satiation (20 min.) with a 32% protein floating extruded feed. Fish that died during the first 6 weeks were replaced from excess fish from the original population that were held in a hoop net in a pond. Dead fish were counted and, if intact, weighed. Gross feed conversion was calculated as the total quantity of feed divided by the total weight of fish harvested plus mortalities. All tanks were harvested by draining on 30 October 2006, 216 days after stocking. Specific growth rate (SGR) was calculated using the formula: $SGR = 100(\ln Wf - \ln Wi)/t$, where ln Wf is the natural log of the final individual weight, ln Wi is the natural log of the initial individual weight, and t is the duration in days.

Hybrid catfish survival and performance was poor (Table 9). Survival did not differ significantly among treatments and averaged 26.7%. Mean individual weight at harvest was independent of stocking rate over the range tested. Gross yield ranged from 0-0.96 kg/m3, did not differ among treatments, and averaged 0.48 kg/m3. Gross feed conversions ranged from 0.6-4.7, and did not differ significantly among treatments, and averaged 2.15. There was a curvilinear decline in feed conversion ratio with increased survival. Higher FCR was observed with lower fish survival. It was difficult to track low-level, chronic mortality accurately to use for adjusting feeding rates. The feeding response by hybrid catfish in the tanks was variable and appeared unpredictable and not as vigorous as with channel catfish. Maximum daily feed consumption (0.2-1.5 kg/tank) was observed from early June in seven tanks to early July in two tanks. Daily feed consumption decreased thereafter and oscillated between 3-50% of the maximum. The reduction in feed consumption was attributed to reduction in fish biomass caused by mortality and the apparent inability of the channel × blue hybrid to adapt to the tank environment.

Dissolved oxygen concentrations exceeded 40% of saturation throughout the experiment. Mean water quality variable concentrations (Table 10) did not differ significantly among stocking rates and were independent of feed and flour inputs. The absence of treatment effects on water quality variables was attributed to the lack of significant differences among treatment total feed input.

The high mortality of the channel × blue hybrid catfish combined with their variable and unpredictable feeding behavior indicates that a tank production system environment is inappropriate for the channel × blue hybrid catfish. Thus, treatment effects were unable to be expressed. Consequently, fish production characteristics and water quality variable responses were similar among treatments. The high chlorophyll *a* and nitrate concentrations observed in all tanks indicated that a combined

Table 9. Specific growth rate, mean weight at harvest, gross and net yields, and survival of channel × blue hybrid catfish after 216 days. Fish were stocked into raceways at 100, 300, or 500 fish/raceway (2.6, 7.9, or 13.1 fish/m^3). At stocking, mean fish weight was 0.069 kg/fish.

Treatment (fish/m^3)	SGR (%)	Mean Weight (kg/fish)	Yield (kg/m^3) Gross	Net	Survival (%)
2.6	0.60	0.33	0.30	- 0.06	26.7
7.9	0.58	0.24	0.60	0.06	33.2
13.1	0.61	0.27	0.55	- 0.12	20.2

Table 10. Mean weekly concentrations of dissolved inorganic nitrogen and phosphorus, total nitrogen and phosphorus, total settleable solids, pH, and chlorophyll *a* in raceways stocked with 2.6, 7.9, or 13.1 channel × blue hybrid catfish/m^3. Means did not vary among treatments ($P > 0.05$).

	Fish/m^3		
Variable	2.6	7.9	13.1
Ammonia (mg NH_4-N/L)	1.36	0.57	1.25
Nitrite (mg NO_2-N/L)	2.74	1.81	2.51
Nitrate (mg NO_3-N/L)	12.75	13.21	11.49
Soluble Reactive Phosphorus (mg PO_4-P/L)	3.37	3.15	1.18
Total Nitrogen (mg/L)	36.20	37.80	36.20
Total Phosphorus (mg PO_4-P/L)	6.97	7.64	4.58
Total Settleable Solids (mL/L)	33.7	44.1	52.4
pH	7.39	7.41	7.43
Chlorophyll *a* (mg/m^3)	1733.50	2421.20	1663.40

photoautotrophic-autotrophic bacteria system controlled tank water quality. Phytoplankton removed dissolved inorganic nitrogen and inorganic carbon. Autotrophic, nitrifying bacteria oxidize ammonia to nitrate in a two-step process mediated by bacteria of two distinct genera. The populations of nitrifying bacteria appeared to have become established contemporaneously between days 21-49 that produced a transitory spike in nitrite-nitrogen concentration and increased nitrate-nitrogen concentration. Total ammonia-nitrogen generally remained low throughout the experiment, with the exception of several transitory spikes in concentration.

The 2007-2008 trial continued to investigate the effect of channel catfish stocking rate on production and water quality in mixed suspended growth (biofloc) tank culture units. Three stocking rates were selected based on the 2005-2007 results.

Nine tanks (35.1 m^2; 28.1 m^3) that have semi-circular ends, are equipped with a center divider, and are lined with HDPE, were filled with well water on 17 March 2007. On 19 March, each tank was fertilized with 0.32 kg 18-46-0 fertilizer. Salt was added to each tank to ensure chloride concentration exceeded 100 mg/L. A continuously operating blower system was installed to aerate tanks instead of an electric paddlewheel aerator. One 1.87-kW blower per three tanks provided air through a diffuser grid on the bottom of each tank. Well water was added only periodically to replace evaporative losses.

On 22 March 2007, tanks were stocked with fingerling

Results at a glance...

- *A zero-exchange, mixed suspended growth (biofloc) system capable of producing up to 4.8 kg of fish/m^2 was developed at the ARS Aquaculture Systems Research Unit. This production is more than 10 times that possible per unit volume of water in traditional channel catfish ponds.*

NWAC 103 strain channel catfish (*Ictalurus punctatus*) that had been vaccinated against *Edwardsiella ictaluri*. Stocking rate was 100, 200, or 300 fish/tank (2.9, 5.7, or 8.5 fish/m^2). Treatments were assigned randomly to tanks. There were three replicates per treatment. At stocking, fish averaged 0.013 kg/fish. Fish were fed daily to apparent satiation with a 32% protein floating extruded feed. Dissolved oxygen and temperature were measured daily, and water quality variables (pH, TAN, NO_2, NO_3, SRP, total settleable solids, and chlorophyll *a*) were measured on a weekly basis. In mid-June, most of the fish in one replicate of the 5.7 fish/m^2 treatment died overnight; an undiagnosed disease was the suspected cause as dissolved oxygen and water quality variable concentrations were within acceptable limits. Data from this replicate were excluded from analyses and reporting.

At harvest, 238 d after stocking, catfish net yield increased linearly from a mean of 1.0 to 3.7 kg/m^3 as stocking rate increased from 2.9 to 8.5 fish/m^2 (Figure 17). Mean final individual weight (semi-log transformed) decreased linearly from a mean of 0.57 to 0.50 kg/fish with increased stocking rate (Table 11). However, specific growth rate of fish did not differ among treatments. Fish survival varied among tanks and ranged from 48 to 73%, but did not differ significantly among treatments. Net fish yield was affected by fish survival, increasing linearly as final fish density increased from 0.9 to 6.7 fish/m^2.

Tank water quality was impacted significantly by channel catfish stocking rate, primarily because feed application increased linearly with stocking rate (Table 12). However, concentrations of water quality variables were within acceptable limits throughout the trial and did not appear to inhibit fish growth. Chlorophyll *a* and total settleable solids mean concentrations did not differ among treatments. Mean nitrite- and total ammonia-nitrogen concentrations did not differ significantly among treatments. Mean nitrate-nitrogen and soluble reactive

Figure 17. Relationship between net yield and stocking rate of channel catfish (*Ictalurus punctatus*) grown in a mixed-suspended growth (bio-floc) system in nine HDPE-lined raceways (35.1 m^2; 28.1 m^3) for 238 days.

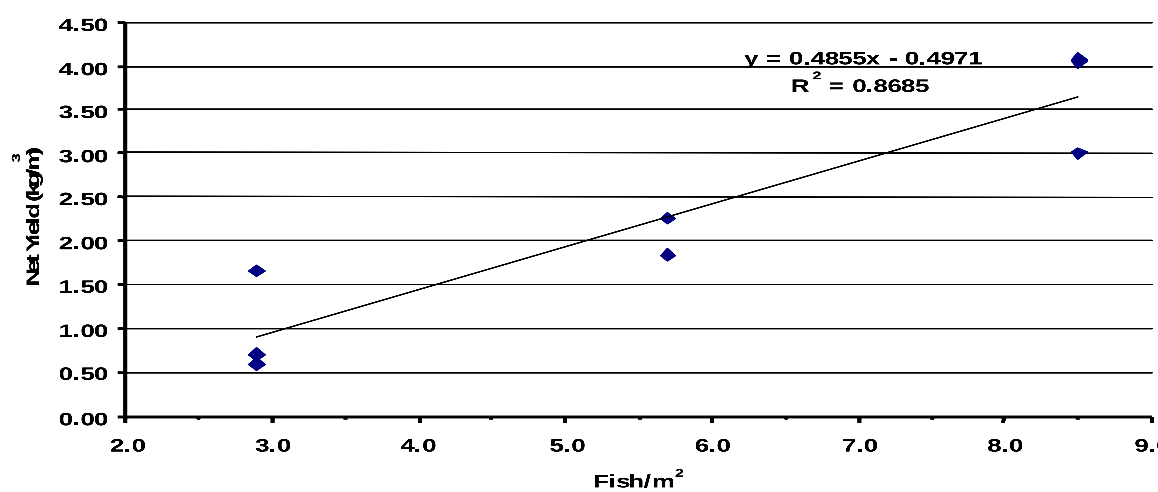


Table 11. Specific growth rate, mean weight at harvest, gross and net yields, and survival of channel catfish after 238 days. Fish were stocked into raceways at 100, 300, or 500 fish/raceway (2.9, 5.7, or 8.5 fish/m^3). At stocking, mean fish weight was 0.013 kg/fish.

Treatment (fish/m^2)	SGR (%)	Mean Weight (kg/fish)	Net Yield (kg/m^3)	FCR	Survival (%)
2.9	1.58	0.57	1.0	2.2	48.2
5.7	1.50	0.47	2.0	1.8	65.9
8.5	1.52	0.50	3.7	1.7	72.7

Table 12. Least squares mean weekly concentrations of dissolved inorganic nitrogen and phosphorus, total settleable solids, pH, and chlorophyll *a* in raceways stocked with 2.9-8.5 channel catfish/m^2.

	Fish/m^2		
Variable	2.9	5.7	8.5
Ammonia (mg NH_4-N/L)	0.30	0.25	0.49
Nitrite (mg NO_2-N/L)	0.25	0.23	0.42
Nitrate (mg NO_3-N/L)	5.98	7.59	19.20
Soluble Reactive Phosphorus (mg PO_4-P/L)	3.10	4.08	5.65
Total Settleable Solids (mL/L)	20.4	31.6	34.2
pH	7.77	7.72	7.51
Chlorophyll *a* (mg/m^3)	690.8	1,014.5	1,047.2

phosphorus increased with increasing stocking rate because of increasing amounts of feed fed. Nitrate-nitrogen began to accumulate in tanks beginning in mid-June in response to nitrification. Increased nitrification was inversely related to mean water pH. Fine-mesh agricultural limestone was added to tanks as needed to maintain pH.

In March 2008, the ARS Aquaculture Systems Research Unit, Pine Bluff, AR, was redirected to the Harry K. Dupree Stuttgart National Aquaculture Research Center, Stuttgart, AR. During April and May, nine HDPE-lined, 18.6-m^2 (15.5 m^3) tanks were constructed to further investigate the effect of channel catfish stocking rate on production and water quality in an intensive mixed-suspended growth system. One 1.87-kW blower per three tanks provided air continuously through a diffuser grid on the bottom of each tank. Tanks were filled on 11-12 June. Tanks were stocked on 18 June 2008 with fingerling NWAC 103 strain channel catfish (*Ictalurus punctatus*) vaccinated against *Edwardsiella ictaluri*. Fingerlings (47 g/fish average weight) were stocked in triplicate tanks at 7.5, 12.5, or 17.5 fish/m^2. Fish are fed daily to apparent satiation with a 32% protein floating extruded feed. Dissolved oxygen and temperature were measured on a daily basis, and water quality variables (pH, TAN, NO_2, NO_3, SRP, settleable solids, total suspended solids, and chlorophyll *a*) were measured weekly. Well water was added periodically to replace evaporative losses. In late July, fish were diagnosed with *Edwardsiella ictaluri*; fish in all tanks were fed for 10 days with medicated feed. Observed mortality from this disease outbreak was low. Beginning in September, sodium bicarbonate was added to tanks as needed to ameliorate decreased water pH. All tanks were harvested by draining on 3 November 2008, 138 d after stocking. All fish in each tank were weighed individually at harvest. Feed conversion ratio was calculated for each replicate as the net yield divided by the total quantity of feed fed.

The net yield of increased linearly from 3.1 to 4.8 kg/m^3 as stocking rate increased from 7.5 to 17.5 fish/m^2 (Figure 18). Mean individual weight at harvest did not differ significantly among treatments and averaged 0.36 kg/fish (Table 13). No significant difference in specific growth rate was detected among treatments (Table 13). Fish survival in the 17.5 fish/m^2 treatment

Figure 18. Relationship between net yield and stocking rate of channel catfish (*Ictalurus punctatus*) grown in a mixed-suspended growth (biofloc) system in nine HDPE-lined tanks (18.6-m^2, 15.5 m^3) for 138 days. At stocking, fingerlings averaged 47 g/fish.

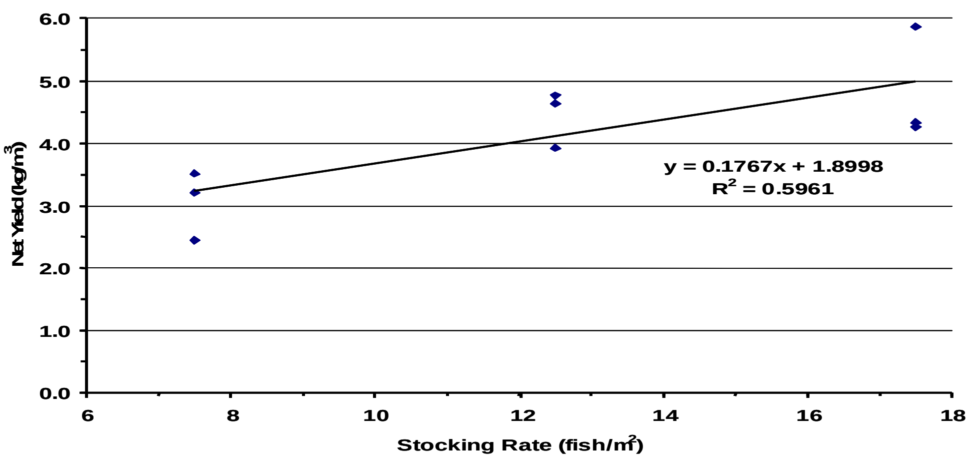


Table 13. Specific growth rate (SGR), mean weight at harvest, net yield, net daily yield, feed conversion ratio (FCR), and survival of channel catfish after 138 days. Fish were stocked into tanks at 7.5, 12.5, or 17.5 fish/m^2. Mean initial fingerling weight = 47 g/fish.

Treatment (fish/m^2)	SGR (%)	Mean Weight (kg/fish)	Net Yield (kg/m^3)	Net Daily Yield (g/m^3/d)	FCR	Survival (%)
7.5	1.56	0.40	3.1	22.2	1.58	96.4
12.5	1.47	0.36	4.4	32.2	1.47	96.3
17.5	1.36	0.31	4.8	35.0	1.63	88.9

averaged 88.9%, significantly lower than the 96.4% and 96.3% survival in the 7.5 and 12.5 fish/m^2 treatments, respectively. Fish survival was consistent among replicates within treatment. Mean daily feed consumption by fish at the 12.5 and 17.5 fish/m^2 stocking rates was 52.8 and 58.5 g/m^3/d, respectively, significantly greater than the 36.1 g/m^3/d of feed consumed by fish at the 7.5 fish/m^2. High feeding rates were sustained from late August through mid-October and averaged 51.4, 79.9, and 79.1 g/m^3/d, for the 7.5, 12.5, and 17.5 fish/m^2 treatments, respectively. Feed conversion ratio and specific growth rate did not differ significantly among treatments.

Mean nitrite- and total ammonia-nitrogen, settleable solids, and total suspended solids concentrations, and pH did not differ significantly among treatments. Cumulative feed addition increased linearly as stocking rate increased. Tank water quality variables were impacted differentially by cumulative feed addition. Mean total suspended solids, nitrate-nitrogen, and soluble reactive phosphorus concentrations increased linearly with increased cumulative feed addition. Mean chlorophyll *a* concentration decreased linearly with increased cumulative feed addition. Nitrate-nitrogen concentration began to increase in early July, indicating the onset of nitrification, and continued to increase throughout the remainder of the experiment. Sodium bicarbonate was added to tanks to mitigate the decreased pH that resulted from nitrification.

Objective 2. *Improve equipment to enhance culture.*

Objective 2a. *Motor-powered U-tube aerator for commercial-scale channel catfish ponds.*

United States Department of Agriculture-Stoneville. A prototype U-tube (Figures 19 and 20) was constructed and installed in a 0.4-ha pond at the National Warmwater Aquaculture Center, Stoneville, Mississippi. The U-tube was fabricated from a 91-cm-diameter, corrugated, galvanized culvert that was installed vertically in a 6-m deep bore hole made in the pond bottom. The unit was powered by a 240-volt, 3-phase, 3.72-kW, helical-geared Flender motor. The motor was vertically mounted on a 91-cm-diameter culvert elbow that was attached to the tube with a 25-cm band clamp. The motor turned a three-vane impeller attached to a 61-cm long × 5-cm diameter unsupported, steel shaft. Water level was maintained at the top of the elbow. The impeller speed was controlled by an in-line, general purpose, open-loop vector, AC-drive (Safetronics Model GP10). With an impeller speed of 150 rpm at 60 Hz, the motor drew 12.7 amps and produced 3.99 kW with a water output of 30.6 m3/min (Table 14).

Pump efficiency increased as impeller speed decreased, but both total output and water velocity decreased. It was determined that the higher velocity was necessary to entrain the volume of air needed to optimize performance. Air was provided by a 3.7-kW, 3-phase blower to diffusers located at or below the mouth of the "down-leg" of the U-tube, which was level with the pond bottom and approximately 1.5 m below the water surface.

Oxygen transfer efficiency tests were conducted using a variety of diffuser types and configurations. The optimum conditions produced an increase in dissolved oxygen of 2.3 mg/L (outflow DO minus inflow DO) and a standard aeration efficiency of 1.01 kg O2/kW·hr. These results were encouraging but less than desired for commercial application.

Two problems were noted during testing of the initial prototype during Year 1. First, it was desired to eliminate obstructions in the tube to enhance water flow. Thus, the impeller shaft was kept relatively short because it had no lateral support near

Figure 19. Prototype U-Tube with pond empty.

Figure 20. Prototype U-Tube with pond full. Discharge can be seen.

Table 14. Operational data for a prototype motor-powered U-tube aerator.

Impeller (rpm)	Motor Amperage	Volts	kW	Water Velocity (m/sec)	Water Output (m^3/min)	Pump Efficiency (m^3/kW · hr)
150	12.7	230	4.00	0.78	30.6	459
125	10.6	205	2.55	0.60	23.8	560
100	8.1	148	1.43	0.45	18.1	759

the end. This resulted in the impeller being located slightly above the bottom of the horizontal (discharge) end of the elbow. As the air:water ratio increased, back-flow from the pond through the mouth of the discharge was observed. This decreased water flow through the tube, and at higher air:water ratios, flow through the tube ceased entirely. Second, using this design, the water level is critical. If the water level dropped below the top of the discharge elbow, flow rate decreased. If the water level rose more than 15 cm above the top of the elbow, the motor could be damaged. For commercial application, the unit should have at least a 60 cm "freeboard" to allow for normal variations in pond water level.

During Year 2 (1 August 2005 – 31 August 2006), two major design modifications were introduced to eliminate the problems identified in Year 1. First, the shaft length was increased to 91 cm. The only concern was the potential for instability with a longer, unsupported shaft. This was not observed. The longer shaft was stable and apparently eliminated the "backflow" problem seen with the shorter shaft. Second, a 60 cm diameter × 41 cm insert was built and installed in the "down" leg of the tube. This did provide a faster water velocity in the "down" leg, allowing for a greater input of air into the system. Tests are now underway to quantify the impact of these modifications. While funding through SRAC ended in July 2006, work on this project is continuing under USDA/ARS funding.

In addition to further testing of the completed modifications, three additional design changes are being considered. First, a submersible motor placed in the mouth of the "down" tube would allow for larger pond water level fluctuations. This would be desirable in commercial applications. Suitable motors are being examined. Second, a venturi will be examined as a means of introducing gas into the water, eliminating the need for a blower. This would both reduce the overall horsepower requirements (increasing efficiency) and eliminate a motor that is a potential cause of failure. Third, the use of pure oxygen (instead of air) will be examined. While the economics may not justify this for routine aeration, the use of pure oxygen in an emergency situation could eliminate the need for a tractor-powered aerator.

Objective 2b. *Low-head, low-speed paddlewheel aerator for crawfish ponds.*

Louisiana State University. A low-speed paddlewheel mixer is being designed and a horizontal circulator/aeration unit was acquired for evaluation in two 1.5 to 2 ha (4 to 5 acre) experimental crawfish ponds at the Aquaculture Research Station in Baton Rouge. Baffle levees are being constructed to configure the ponds so that water can be recirculated. Mixing patterns and water quality will be monitored during the 2006-2007 crawfish production cycle.

Because of rainfall during the summer of 2006 ponds would not sufficiently dry to support heavy equipment required to laser-level ponds and construct internal baffles necessary install paddlewheel mixers. Weather conditions were more favorable in during summer 2007, and baffles were constructed in two large experimental crawfish ponds to accommodate a paddlewheel mixer and a submersible turbine mixer, respectively, in each pond. Mixing patterns, water quality and nutrient budgets will be determined in the mixed and non-mixed control pond during 2007-2008 crawfish production season.

Paddlewheel mixer/blending units were installed in three large experimental crawfish ponds at the Aquaculture Research Station each pond containing earthen baffles to re-circulate and mix water throughout each pond. Spatial distribution of dissolved oxygen (DO) in morning and afternoon was evaluated in March, May and June at 18 sampling stations in each pond. Mixers were operated continuously and DO were measured at each station in the morning and afternoon. Spatial variability in DO concentration throughout the ponds provided an index of the degree of water mixing. In March when significant amounts of cultivated rice forage was present and phtyoplankton density was low, oxygen concentration was more evenly distributed in mixed ponds (coefficient of variation, CV, associated with mean DO = 11%) than in non-mixed ponds (CV = 29%). However, in May and June when rice forage had been depleted and phytoplankton biomass increased, the variability of DO in mixed ponds (CV = 23%) was high as in non-mixed ponds (CV = 25%).

Objective 2c. *Low-power, electrically-enhanced seine to harvest market-sized channel catfish from commercial-scale ponds.*

Mississippi State University. The primary objectives for the first year of research were to design, manufacture, and test the electrical components required to build the individual modules that will power the electrically-enhanced seine. Three models of the power supply and electrical circuitry were designed, manufactured, and tested during this year. Through this process, the total weight of the electrical components needed to build an electrical module has been reduced over 60%. The power supply and electrical circuitry were miniaturized to fit on a 7.6 cm × 12.7 cm circuit board. A safety circuit designed to switch off the electrical power to a panel as it comes out of the water was added to the circuit board of the latest model of the system. The results of tests conducted in concrete vats indicate that the low powered electrical system (electrodes with no net) will repel adult catfish away from the attached electrodes. However, the system currently appears to be underpowered.

The miniature fish stimulator and power supply module was redesigned based on results of the first year. The system was further reduced in weight while maintaining the developed safety features. The output transformer was redesigned to operate at a higher frequency. In addition, the operating power was reduced from 60 to 10 watts. The results of vat tests using production-sized catfish indicated that the unit is only moderately effective as constructed. It was recently determined that the redesigned output transformer had a lower voltage than specified because of a tooling error by the manufacturer. Efforts are currently underway to get the manufacturer to correct this problem. The power supply and electrical circuitry will be re-tested once properly manufactured parts are obtained.

During the fall of 2006, efforts to eliminate manufacturing design flaws in the miniature transformer were unsuccessful; consequently, further development of the miniature transformer has been abandoned. During 2007, two new designs for a miniature fish stimulator were completed and the prototype units are currently being tested. Prototype-I operates without a transformer thus is the lightweight design. It is designed to stimulate catfish using a low voltage current produced by two AA-batteries. Prototype-II uses a power transformer to generate a high voltage AC pulse to stimulate catfish. The strength of the output current produced by both units can be controlled. The objectives of the new designs are to determine the efficacy of low-voltage system and to investigate the extent of the capabilities of the traditional transformer design. The ultimate goal is to develop an optimal design that is both lightweight and effective.

Problems were identified with both Prototype-I and Prototype-II fish stimulators when they were tested in concrete vats stocked with varying numbers of adult-sized catfish. Prototype-I (no transformer, low voltage, and light-weight) was not effective. Fish appeared to sense the presences of the electrodes but were able to easily swim past them. The design of this unit is being reevaluated; it will likely be abandoned. Prototype-II (high voltage with a transformer) was only moderately effect in repelling approaching fish. Also, durability issues with the unit must be resolved.

Modifications to Prototype-I and Prototype-II fish stimulators were unsuccessful in improving their effectiveness in repelling adult catfish away from the energized electrodes. Consequently, we have concluded that we will abandon our efforts to reduce the complexity, size, and weight of the electrical components needed to build an electrically enhanced seine.

Objective 3. *Assess energy, material, and economic efficiency of production systems.*

Objective 3a. *Quantify energy, protein, and water use in traditional systems for channel catfish culture.*

Auburn University. During 2005, data on electricity and fuel use were obtained monthly from four catfish farmers. However, in early 2006, the graduate student unintentionally caused slight, cosmetic damage to some equipment on one of the farms. All four farmers subsequently refused to cooperate further.

Data on the cost of electricity and fuel used on catfish farms are now being sought by other means. Twelve farmers, two hatchery owner-operators, one processing manager, and one seining crew manager agreed to participate in the study. In early summer of 2006, questionnaires about energy use were sent to the new cooperators. We have received full responses from four farmers, one seining crew manager, one processor, and no hatchery operators. Data collection was delayed by the onset of the peak of the farming season, and will continue again in the fall when people are more accessible. We anticipate full participation except for the two farmers that have been unresponsive.

The questionnaires include items on total use of electrical power and petroleum specific to each aspect of raising channel catfish. The questionnaires

Results at a glance...

- *Indicators of the efficiency of resource use in aquaculture have been developed and are being used by several environmental advocacy groups in assessing the sustainability of aquacultural production. Direct energy use for production of channel catfish in Alabama was 3.059 kW · hr/kg with 44% of energy used on farms.*

make sure that the respondent lists only energy use for catfish. The questionnaires also include items on fish survival, food use, and yields where appropriate.

During late 2006 and early 2007, we obtained the responses to the questionnaire mentioned above. In all, we obtained amounts of gasoline, diesel fuel, natural gas, propane, and electricity used and production achieved over a 12-month period for one pond construction firm, two hatcheries, four farms, a feed mill, a custom harvesting crew, and a processing plant. These data were incomplete and we had to visit the respondents and interview them to obtain sufficient information.

Energy for pond construction was from diesel fuel. The contractor provided data on fuel used and area of ponds constructed in one year. This allowed the calculation of energy use per hectare of pond construction, and the energy expenditure was amortized over 20 years, the estimated service life of a pond. Hatchery operations used only electricity. The feed mill used mainly natural gas as an energy source. About 80% of energy used on farms was from electricity and about 20% from diesel, gasoline, and propane. The harvesting operation relied on vehicles and other machines powered by diesel fuel. Electricity was the sole energy source for the processing plant. The kilocalories of hydrocarbon fuels used were converted to kilowatt · hours (kW · hr) so that these inputs could be easily combined with electrical energy.

The energy use estimates allowed calculation of energy expenditures (Table 15) incurred at each stage in the production chain for one kilogram of live catfish (completely processed). The greatest proportion of energy was used on farms and mainly for feeding fish and applying aeration to ponds by mechanical means. Manufacturing enough feed to produce 1 kg of fish required about 62% as much energy as used on farms to grow out 1 kg of fish. Processing required about half as much energy as feed manufacturing. The smallest amount of energy was used for harvesting. Pond construction required a large quantity of energy, but ponds last a long time. Thus, when energy for pond construction was spread over 20 years, it was only slightly greater than the energy used for harvesting. Hatchery operation was similar to pond construction with respect to energy use per kilogram of catfish. Estimation of the energy expended in shipping processed fish and maintaining them in refrigerated storage until used by consumers was not attempted. Moreover, energy consumed indirectly for producing feed ingredients, and for producing machines and fuel used in catfish production was not considered in this study.

Table 15. Direct energy use in channel catfish farming in Alabama.

Activity	Energy use (kW · h/kg)	Percentage
Pond construction	0.154	5.03
Hatchery	0.185	6.05
Feed	0.843	27.56
Grow-out	1.362	44.52
Harvest	0.092	3.01
Processing	0.423	13.83
Total	3.059	100.0

One kilogram of live catfish, the production of which required 2,630 kilocalories of energy directly, provides about 600 g or edible meat containing about 912 kilocalories (or 912 calories as referred to in human diets). This is an energy in:energy out ratio of about 3:1. Of course the ratio would be much greater if all indirect energy costs mentioned above were included.

At the farm level, the energy to produce 1 kg of fish costs about \$0.127. This is a substantial expense considering the farm gate price of catfish is only \$1.30 to \$1.60 per kilogram. The total cost of energy for producing and processing 1 kg of live catfish was about \$0.251.

It is doubtful that it would be possible to greatly reduce energy use for feed manufacturing or fish processing. About half of the energy use was on farms, and most of this energy went to power aerators. Improvement in the efficiency of aeration appears to be an opportunity for reducing energy use on farms. Moreover, improvement in the feed conversion ratio (FCR) in grow-out ponds could reduce the contribution of feed manufacturing to energy use/kg fish.

Investigations of water use require definitions of water use terminology. Total water use should refer to the amount of water applied to an aquaculture system in rainfall, runoff, and other natural processes and by management intervention, such as water added by pumping or other mechanical means.

Consumptive water use should represent the reduction in surface runoff caused by an aquaculture facility on a watershed. Less runoff equates to less stream flow for downstream water users. In addition, all freshwater withdrawn from aquifers by wells should be included as a consumptive use, because this water would not be available to other users of ground water in the area. Although ground water is re-charged by infiltration, it sometimes is removed by wells at a rate exceeding recharge. This diminishes the amount of water available from wells in the area. Ground water depletion usually is more serious in arid than in humid climates, but even in humid climates, availability of water from wells may be reduced during the dry season and especially during droughts. Consumptive water could be determined as follows:

Consumptive water use = Reduction in stream flow + Water withdrawn from wells

The amount of ground water pumped or derived by artesian flow from wells should be indicated as a separate variable for ground water use. This is a major issue in many regions. Spring flow should not be included, for springs discharge onto the land surface naturally.

Non-consumptive water use should refer to water that passes through aquaculture facilities and is still available to other users downstream. It could be calculated as follows:

Non-consumptive water use = Total water use – Consumptive water use

A water use index relating the amount of water used in an aquaculture facility to production could be useful. Although this index could be calculated for both total and consumptive water use, the consumptive water use index would be most meaningful. The index could be calculated as shown below (mt = metric tons):

Water use index (m^3/mt) = consumptive water use (m^3) ÷ production (mt)

An index of the economic value of water used in aquaculture should be available. This variable could be determined with the following equation:

Water value index (\$/m^3) = [production (mt) × crop value (\$/mt)] ÷ consumptive water use (m^3)

Studies of protein use in catfish farming also will require some indices of protein and fish meal use. The following indices have been developed based upon the feed conversion ratio (FCR):

Protein conversion ratio (PCR), an index of the amount of feed protein needed per unit of production: PCR = FCR × [feed protein (%) ÷ 100]

Protein equivalence (PE), the ratio of feed protein to aquaculture protein produced: PE = FCR × [Feed protein (%) ÷ protein concentration in live culture species (%)]

Fish meal conversion ratio (FMCR), the ratio of fish meal in feed to aquacultural production: FMCR = FCR × [fish meal in feed (%) ÷ 100]

Live fish equivalence of fish meal (LFE), the ratio of live fish needed for the fish meal in feed to aquacultural production: LFE = FMCR × 4.5

The Auburn University component of this project was completed in 2007. However, during 2008, two manuscripts were written and published, and a paper describing the results of the energy study was presented at a scientific meeting.

Objective 3b. *Develop and evaluate economic and financial models of existing and improved production practices and technologies.*

University of Arkansas at Pine Bluff. Cash flow budgets were developed for five farm sizes: 24 ha, 103 ha, 147 ha, and 407 ha. Validation tests were conducted against cash flow budgets of commercial catfish farms. The effect of varying equity levels, from 0% to 100% was measured across the five farm sizes (Figures 21 and 22). Schedules of cash flow and cash flow risk were developed in 10% increments from 0% to 100% equity for each farm size. With 100% equity, monthly cash flows were positive for all months except February for all farm sizes. Cash flow risk ranged from 0.28 to 0.31 when compared with total cash inflow and from 0.39 to 0.44 when compared against operating expenses. With 100% financing, only the larger farm sizes cash flowed, but at very high levels of risk (0.0008 compared to cash inflow and 0.0012 compared against operating expenses).

A survey was conducted to gather data from lenders with portfolios in catfish, row crop, and livestock loans. A total of 80 banks (6 in Alabama, 23 in Arkansas, 36 in Mississippi, and 15 in Louisiana) have been included in the sample. Of these, 32 have catfish loans and 48 have agriculture, but not catfish loans. Data obtained from the survey was used to identify the range of lending programs, structures, and repayment plans commonly used for catfish,

Results at a glance...

- *Detailed cash flow budgets were developed for existing and new startup catfish farms under a variety of equity positions. Budgets measure cash flow risk for varying farm sizes with different levels of financing and different management strategies.*
- *Current cash flow budgets showed a much longer time period to develop positive cash flow than for budgets developed more than 20 years ago. This finding explains financial difficulties for farms that entered catfish production in the 1990s. Startup catfish farms require a 4-year cash flow planning period. Purchasing stockers in the first year alleviates cash flow problems. This study identified sizes and stocking densities of stockers that result in positive cash flow in the early years of a catfish farm.*

Figure 21. Cash flow coverage ratio across farm sizes with 30%, 60%, and 90% financing.

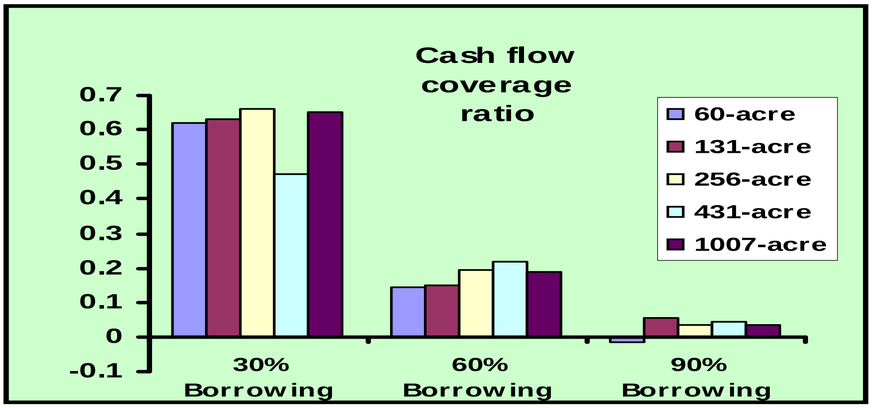
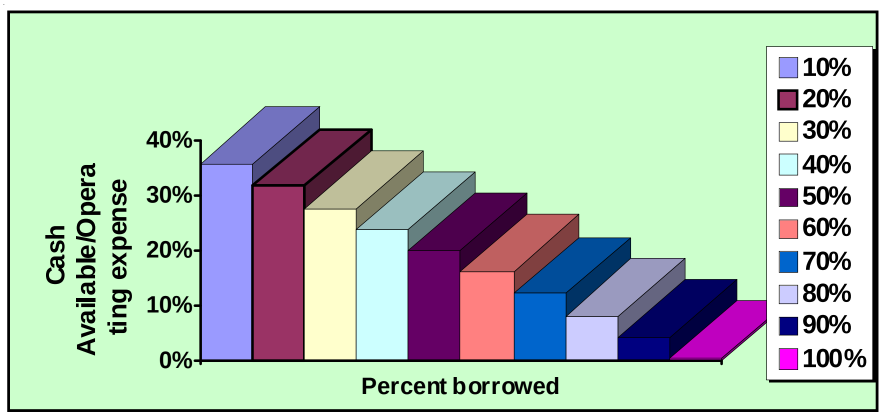


Figure 22. Cash availability compared to operating expenses on a 256-acre farm with levels of financing from 10% to 100%.



loans as well as those commonly used in other types of agriculture. These financial lending scenarios will then be applied sequentially to the cash flow budgets to assess the effects on cash flow and repayment capacity.

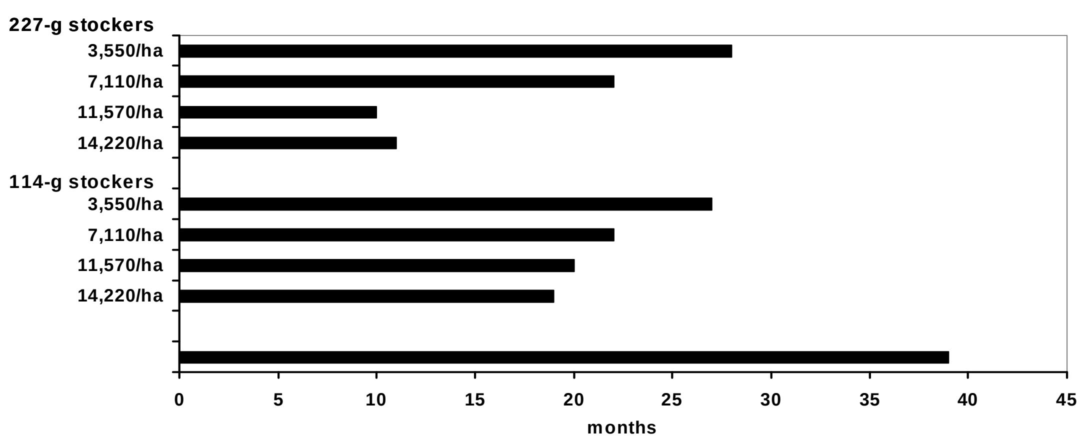
The initial cash flow budgets were developed for existing farm situations, farms that had been in business for a number of years. However, startup catfish farms require four years to build production to levels that generate adequate cash flow, if initial stockings are based on 12.7-cm fingerlings. Additional cash flow budgets were constructed to measure effects of the use of varying percentages and sizes of stockers on cash flow. The cash flow budgets developed for the 24 ha, 103 ha, 147 ha, and 407 ha catfish farms were further modified to reflect cash flow for startup catfish businesses. The effect of equity position was varied from 0% to 100% in 10% increments to evaluate its effect on startup catfish businesses.

These budgets are multi-year budgets with no revenue in Year 1 because a startup farm that stocks fingerlings will have no revenue in Year 1. These budgets showed that, for all five farm sizes, cash flow did not become positive until Year 4. These results, based on current cash flow conditions, showed a much longer time period to develop positive cash flow than previous cash flow budgets (that are more than 20 years old). This finding explains financial difficulties of farms that entered catfish production in the 1990s. Startup catfish farms require a 4-year cash flow planning period.

Use of stockers improved cash flow and reduced the number of years required to reach adequate cash flow coverage, with the degree of the effect varying with the size of stockers used and the percentage of total stocking devoted to stockers. A startup catfish farm requires 39 months to achieve a positive cash flow (Figure 23). Stocking ponds with 114-g catfish stockers reduces the number of months to achieve positive cash flow to 19-27 months. Stocking 14,220 stockers/ha achieved the shortest time, 19 months. Stocking at lower rates lengthens this time to 20 (11,570/ha), 22 (7,110/ha), and 27 (3,550/ha). Stocking 227-g stockers at the higher rates (14,220/ha and 11,570/ha) resulted in positive cash flow in the first year (10 and 11 months). However, the lower stocking rates of 7,110/ha and 3,550/ha did not improve the time to achieve positive cash flow over that of 114-g stockers, but would be more costly. Thus, if a farm must generate positive net cash flow in the first year, 227-g stockers should be used at 11,570/ha. If a positive cash flow is not needed until the second year, 114-g stockers can be used at either 11,570/ha or 14,220/ha. These results were robust across the five farm sizes modeled.

Two mathematical programming economics models have been developed that incorporate grow-out and fingerling production activities. The models maximized net farm income subject to constraints that include: quantity of operating capital, the number of ponds available, farm size, appropriate balance and transfer rows, and non-negativity conditions. Fingerlings were produced either with or without thinning at different stocking densities. Results showed that the optimal size of fingerling to under-stock was 12.7 cm. On-farm production of fingerlings was selected across all farm sizes but the fingerling production technique selected varied with farm size. Models of larger farm sizes began to thin fingerling production ponds, while models of smaller farm sizes produced fingerlings only without thinning.

Figure 23. Length of time (months) required to achieve positive cash flow with no stockers and various stocker options.



When farm size was treated as endogenous, the optimal size of a catfish farm was 404-water ha. Sensitivity analyses suggested that net returns were sensitive to changes in the key parameters of the model, whereas the optimal size of fingerling to under-stock was robust to variations in the model's parameters. In multiple-batch production, profits were maximized with on-farm production of 12.7-cm fingerlings.

We developed a second multi-period mixed integer-programming model that included six different types of stockers (stockers produced from 6.7-cm fingerlings stocked at 50,000, 100,000, and 150,000/ha, and from 9-cm, 11-cm and 13-cm fingerlings stocked at 100,000/ha) and three different sizes of fingerlings (7.6-cm, 12.7-cm, and 17.8-cm). The results revealed that nearly one-third of the area available for catfish grow-out production should be allocated to foodfish production from fingerlings and two-thirds from stockers. Profits were maximized with on-farm production of 12.7-cm fingerlings, and stockers produced from 9-cm and 11-cm fingerlings stocked at 100,000/ha (Table 16). Sensitivity analyses suggested that the results were sensitive to varying levels of operating capital in that a decrease in the availability of operating capital would result in an increase of foodfish production from fingerlings and a decrease in foodfish production from stockers. Increased availability of operating capital increased on-farm production of stockers for subsequent use in foodfish grow-out. Results of this analysis provide guidelines for farmers related to trade-offs between the use of fingerlings and stocker catfish on farms.

The mathematical programming models of fingerling and stocker production were extended to incorporate the cash flows required as indicated by the cash flow budgets for the various farm sizes and equity positions. Results show that cash flow position affects the selection of optimal management strategies.

The models demonstrated that, when lenders restrict access to operating capital (for example, when lending limits decrease as the price of fish decreases and the value of assets on the balance sheet falls), and there are cash shortfalls, farms are forced to take ponds out of production. The effect is more pronounced on smaller farms. Across all farm sizes, the financial

Table 16. Results of simulations of farm size and pond allocation to stockers and fingerlings.

				Fry Stocking Rates (fry/ha)	Stockers		
	Pond Allocation			No Thinning		Fingerlings Stocking Rate (100,000/ha)	
Farm Size	Stockers	Fingerlings	Fingerlings Stocked	543,334	1,398,990	9-cm	11-cm
(ha)	(%)	(%)	(cm)	(%)	(%)	(%)	(%)
40	71	29	12.7	0	100	96	4
80	71	29	12.7	0	100	100	0
120	71	29	12.7	0	100	99	1
160	70	30	12.7	0	100	95	5
200	66	34	12.7	1	100	81	19
240	62	38	12.7	25	75	70	30

condition of farms became particularly acute at cash flow restrictions greater than about 30%.

Cash flow problems when total operating capital was not restricted resulted in changes to the management plan on the farm. The optimal strategies in the base models prior to imposing cash flow restrictions, were foodfish production from fingerlings on the smaller farms and foodfish production from stockers on the larger farms. As cash flow was restricted, the smaller farms switched to stocking smaller fingerlings and the larger farms switched to stocking fingerlings instead of stockers. Thus, the feasibility of a stocker phase on catfish farms is affected by both the overall level of operating capital and cash flow limitations.

Results at a glance...

- *Cash flow budgets developed in this project were used extensively in 2009 to 1) update cash flow simulator-spreadsheet models available online; 2) conduct financial management workshops statewide in Arkansas; and 3) provide one-on-one financial assistance to catfish farmers from late 2008 through 2009. These budgets and models were used extensively by Arkansas catfish farmers to plan management strategies to attempt to survive the extremely high feed prices of 2008-2009. Farmers have reported that these models were helpful in decision-making through 2009.*

Additional sets of mathematical programming models were developed that incorporated a variety of lending strategies along with various production and marketing strategies. The models were most sensitive to the availability of credit in the first quarter of the year, typically a quarter with fewer sales, but increased costs of purchasing fingerlings. However, restricted market access results in increased borrowing in subsequent quarters, decreasing net returns. These models can be used to provide guidance to farmers on terms of lending that are best suited for their financial situation.

A Just-Pope catfish production function was used to estimate minimum catfish prices and maximum feed prices at which various feeding rates would be economically efficient. Optimal stocking and feeding rates were estimated for very low catfish price levels. Low catfish prices require lower stocking and feeding rates to operate at profit-maximizing levels. Stocking rates below 10,000/ha will not generate adequate revenue to cover debt-servicing requirements for long-term capital investment loans. Thus, farmers must adopt management strategies that will satisfy the multiple business requirements of servicing debt and meeting fish delivery schedules. The results of this analysis provide guidance on the relationships among prices of catfish and feed, with stocking and feeding rates, to provide a basis for these decisions.

IMPACTS

Studies of Partitioned Aquaculture Systems developed at Clemson University revealed that channel catfish fingerling growth can be significantly intensified and accelerated in these systems, yielding fingerlings in excess of 100 gm in size within a 120 to 140 day growing season at demonstrated carrying capacities of 4200 kg/ha. The "split-pond" modification of the PAS systems used at Mississippi State University also allowed excellent grow-out of stocker-sized fish to harvestable size. Several commercial catfish farmers are currently building split-ponds for commercial use in the 2010 production year.

Net yield of channel catfish in intensively managed earthen ponds ranges from 0.4-0.7 kg/m^3, but more intensive production systems are required to increase catfish net yields further. A zero exchange, mixed suspended growth (biofloc) production system was used to investigate the effect of channel catfish stocking rate on production. Channel catfish net yield increased curvilinearly from 1.0 to 4.8 kg/m^3 as the stocking rate increased from 2.9 to 17.5 fish/m^2. High feeding rates (24.2 to 79.9 g/m^3/d) were sustained without impacting water quality negatively. This research demonstrated that channel catfish yield could be increased by using the zero exchange, mixed suspended growth (biofloc) system.

The prototype, motor-powered, U-tube aerator being developed by United States Department of Agriculture-Stoneville can move up to 759 m^3/water/kW · hr, but the oxygen transfer efficiency must be improved for commercial application.

Studies at Auburn University have resulted in a number of indicators of sustainable aquaculture that are already being used by the Global Aquaculture Alliance and the World Wildlife Fund in evaluating the ecological efficiency of different production systems. Studies of energy use indicated that a total of 3.059 kW · hr energy is used to produce and process 1 kg of live catfish. Grow-out of fish on farms account for nearly half of energy use and feed production accounts for another 30% of energy use.

The semi-confinement units tested at the University of Arkansas at Pine Bluff increased the yield of fingerling catfish in ponds and has commercial potential. A similar system is being tested at a commercial facility for grow-out of fingerlings.

Economic analyses done at University of Arkansas at Pine Bluff revealed that the optimum size of a catfish pond was about 400 ha of water surface area. Cash flow budgets have been developed for five farm sizes, for existing and startup farming operations with no stockers, 114-g and 227-g stockers, stocked at four different rates for 11 different financing options, for a total of 550 budgets. These spreadsheet model budgets have been used extensively to provide direct financial assistance to catfish farmers through the difficult financial times of recent years. A number of workshops on cash-flow based management have been held to aid farmers to make decisions related to survival of their farm businesses. The cash flow budgets developed in this project were used extensively in 2009 to: 1) update cash flow simulator-spreadsheet models available online; 2) conduct financial management workshops statewide in 2009; and 3) provide one-on-one financial assistance to catfish farmers from late 2008 through 2009. These budgets and models are in use in Arkansas by catfish farmers to plan management strategies to attempt to survive the extremely high feed prices of 2008-2009. Farmers have reported that these models were helpful in decision-making through 2009.

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED

Publications in print

Beecham, R. V., C. D. Minchew, and B. Small. 2006. Using portable lactate and glucose meters for catfish research: an inexpensive alternative to established laboratory techniques? North American Journal of Aquaculture 68:291-295.

Beecham, R. V., C. D. Minchew, and G. R. Parsons. 2007. Comparative swimming performance of juvenile pond-cultured and wild-caught channel catfish. North American Journal of Fisheries Management 27:729-734.

Beecham, R. V., C. D. Minchew, and G. R. Parsons. 2007. Fatigue and recovery of blue and channel catfish fingerlings under flow and no-flow conditions. North Journal of Aquaculture 69:244-249.

Bouras, D. and C. R. Engle. 2007. Optimal size of fingerling to understock in catfish growout ponds: an application of a multiperiod integer programming model. Aquaculture Economics and Management 11(2):195-210.

Boyd, C. E. 2005. Feed efficiency indicators for responsible aquaculture. Global Aquaculture Advocate 8(6):73-74.
Boyd, C. E. 2005. Ground water and wells. Global Aquaculture Advocate 8(3):62-63.
Boyd, C. E. 2005. Water use in aquaculture. World Aquaculture 36(3):12-15, 70.
Boyd, C. E. 2006. Estimates of bottom soil and effluent load of phosphorus at a semi-intensive marine shrimp farm. Journal of the World Aquaculture Society 37(1):41-47.
Boyd, C. E. and M. Polioudakis. 2006. Land use for aquaculture production. Global Aquaculture Advocate 9(2):64-65.
Boyd, C. E., C. S. Tucker, A. McNevin, K. Bostick, and J. Clay. 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. Reviews in Fisheries Science 15:327-360.
Boyd, C. E., M. Polioudakis, and G. N. Whitis. 2008. Direct energy use in channel catfish production. Global Aquaculture Advocate 11(4):48-50.
Boyd, C. E., H. Pine, C. A. Boyd, and R. Hulcher. 2008. Excess runoff contribution to daily discharge frequency of channel catfish farms in Alabama. Journal of the World Aquaculture Society 39(4):490-499.
Dasgupta, S. and C. Engle. 2007. Impact of low catfish prices on economically efficient feeding and optimal stocking densities of channel catfish, Ictalurus punctatus, in multi-batch production in the U.S. south. Journal of Applied Aquaculture 19(2):67-82.
Green, B. W. 2009. Effect of channel catfish stocking rate on yield and water quality in an intensive, mixed suspended-growth production system. North American Journal of Aquaculture 72:97-106.
Hall, S. G., R. R. Price, A. Mudgundi, and N. Mandhani. 2006. Autonomous vehicles to measure water quality in multiple dimensions in coastal areas. In: Xu, Y.J. and V. P. Singh, Coastal Environment and Water Quality, Water Resources Publications, pp. 285-292.
Hargreaves, J. A. 2006. Photosynthetic suspended-growth systems in aquaculture. Aquacultural Engineering 34:344-363.
Minchew, C. D., S. D. To, K. K. McDill, and R. V. Beecham. 2004. Harvest of channel catfish with an electrically-enhanced seine. Journal of the World Aquaculture Society 35(4):34-36.
Minchew, C. D., M. W. Fondren, E. H. Robinson, J. W. Watson, and C. W. Taylor. 2007. Advances in Catfish Harvesting Gear: Seines and Live Cars. Southern Regional Aquaculture Center Publication 1805.
Minchew, C. D., Beecham, R. V., P. R. Pearson, B. W. Green, J. M. Kim, S. B. Bailey. 2007. The effects of harvesting and hauling on the blood physiology and fillet quality of food-size channel catfish. North American Journal of Aquaculture 69:373-380.
Pearson, P. R., S. E. Duke, B. W. Green, C. D. Minchew, R. V. Beecham, and J. M. Kim. 2006. Evaluation of a diffused oxygen aeration system under on-farm harvest conditions. North American Journal of Aquaculture 68:47-52.
Romaire, R.P. and G. Merry. 2007. Effects of mechanical aeration on water quality in crawfish ponds. Journal of Applied Aquaculture 19(3):61-75.
Saidu, M and S. Hall. 2006. Automated temperature-controlled recirculation systems. Global Aquaculture Advocate 9(3):40.
Tucker, C. S. 2008. Misuses of sodium bicarbonate in aquaculture. Global Aquaculture Advocate 11(4): 60-61.
Tucker, C.S. and L.R. D'Abramo. 2008. Managing high pH in freshwater ponds. Southern Regional Aquaculture Center Publication 4604.
Tucker, C.S. 2008. A novel, split-pond system for growing catfish. The Catfish Journal 22(4):18-19.
Tucker, C. S. and J. A. Hargreaves. 2006. Water-level management and BMPs cut water use and pond effluents. Global Aquaculture Advocate 9(3):50-51.
Tucker, C. S. and J. A. Hargreaves (editors). 2008. Environmental Best Management Practices for Aquaculture. Blackwell Publishing, Ames, Iowa. 582 pages.
Tucker, C.S., J.A. Hargreaves, and C.E. Boyd. 2008. United States aquaculture and the environment. Pages 3-54 in "Environmental Best Management Practices for Aquaculture." Blackwell, Ames, Iowa.
Tucker, C.S., J.A. Hargreaves, and C.E. Boyd. 2008. Best management practices for freshwater pond aquaculture. Pages 151-226 in "Environmental Best Management Practices for Aquaculture." Blackwell, Ames, Iowa.
Tucker, C.S., S.K. Kingsbury, and C.C. Mischke. 2009. Bacterial bioaugmentation of channel catfish ponds. North American Journal of Aquaculture 71:315-319.

Presentations

Beecham, R. V., C. D. Minchew, and G. R. Parsons. 2005. Non-horizontal swimming performance of blue and channel catfish fingerlings. America Fisheries Society Annual Meeting, September 11-15, Anchorage, Alaska.

Beecham, R. V., P. R. Pearson, C. D. Minchew, S. B. Bailey, and M. B. Flanagan. 2007. A liquid oxygen calculator for fasted channel catfish. Aquaculture 2007, February 26-March 2, San Antonio, Texas.

Beecham, R.V., M.J. Griffin, S.B. Bailey, D. Wise, M. Mauel, L. Pote, and C.D. Minchew. 2008. The effects of proliferative gill disease (PGD) on the blood physiology of channel, blue, and hybrid (blue × channel) catfish fingerlings. World Aquaculture Society, Aquaculture America, February 9-12, Orlando, Florida.

Beecham, R.V., P.R. Pearson, G.R. Parsons, and C.D. Minchew. 2008. Oxygen consumption rate and metabolism of blue, Ictalurus furcatus, and channel, I. punctatus, catfish. World Aquaculture Society, Aquaculture America, February 9-12, Orlando, Florida.

Bouras, D. and C. R. Engle. 2006. Optimal size of fingerling to understock in multiple-batch catfish farms. Abstract. Annual Meeting of the U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Las Vegas.

Bouras, D. and C. R. Engle. 2007. The economic trade-offs between stocking fingerlings and stockers: a mixed integer multi-period programming approach. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Boyd, C. E. 2006. Indicators for assessing environmental performance of aquaculture. AQUA 2006, May 9-13, Florence, Italy.

Boyd, C. E. 2007. Water, land, protein, and energy use in channel catfish farms. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Boyd, C. E. 2007. Environmental issues in small-scale aquaculture. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Boyd, C. E., H. Pine, and R. Hulcher. 2007. Excess runoff definition for identification for concentrated aquatic animal production facilities in Alabama, USA. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Boyd, C. E., E. Polioudakis, and G. N. Whitis. 2008. Direct energy use in channel catfish production. Aquaculture America 2008, February 9-12, Orlando, Florida.

Brune, D. E., K. Kirk, and A. G. Eversole. 2006. Partitioned aquaculture systems. Lectures delivered at the European Union Sponsored Special Course on Recirculating Aquaculture, Wageningen University, Netherlands.

Brune, D. E., K. Renwick, and A. G. Eversole. 2006. Channel catfish fingerling production in the partitioned aquaculture system. Annual Catfish Farmers Meeting, San Antonio, Texas.

Brune, D. E. 2007. Update on Aquaculture at Clemson. Meeting of the South Carolina Aquaculture Association, Columbia, South Carolina, February 2007.

Brune, D. E. and T. Wells. 2008. High-rate catfish fingerling production in the partitioned aquaculture system. Aquaculture America 2008, Orlando, Florida.

Chambers, J. P., D. Minchew, and R. Beecham. 2004. AquaScannerTM Catfish Sonar: Acoustic Instrumentation for Aquaculture. Mississippi Intellectual Property Forum, November 30-December 1, Jackson, Mississippi.

Engle, C. R. 2008. Stocking and feeding rates and farm costs with high feed prices. Catfish producer meeting, Lake Village, AR. March 11, 2008.

Engle, C. R. 2008. Stocking and feeding rates and farm costs with high feed prices. Catfish producer meeting, Jonesboro, AR. March 13, 2008.

Engle, C. R., D. Heikes, and S. Pomerleau. 2008. How do I manage my farm with high feed prices? Poster presentation at Arkansas Aquaculture 2008, annual meeting of the Catfish Farmers of Arkansas, Hot Springs, Arkansas. Jan. 30 – Feb. 2.

Engle, C. R., D. Heikes, and S. Pomerleau. 2008. How do I manage my farm with high feed prices? Poster presentation at The Catfish Farming Trade Show, Greenville, Mississippi. Feb. 7.

Engle, C.R. 2009. The effect of feed formula and feeding frequency (daily vs. every other day) on production costs for catfish grown at different densities. Southeast Area Catfish Workshop, Lake Village, April 2, 2009.

Engle, C.R. 2009. The economics of producing catfish: a review of what we know about stocking densities, sizes, and costs. Catfish Farmers of America Research Symposium, Natchez, Mississippi.

Green, B. 2007. Production of catfish in a microbial-based system. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, Book of Abstracts p. 359, San Antonio, Texas.

Green, B. W. 2008. Effect of channel catfish stocking rate on yield and water quality in an intensive production system. Aquaculture America 2008, February 9-12, Orlando, Florida.

Hargreaves, J. and W.H. Wong. 2007. The effects of solids concentration on performance of a biofloc system for tilapia. Abstracts: Aquaculture 2007, The International Triennial Meeting of the World Aquaculture Society, National Shellfisheries Association, and American Fisheries Society Fish Culture Section, 2007 February 26 March 2, San Antonio, Texas.

Massingill, M. and D. E. Brune. 2008. High-rate zero-discharge aquaculture in the partitioned aquaculture system. Presented to the Workshop on Aquaculture Development in the Azores, Horta, Azores, Portugal.

Minchew, C. D., R. V. Beecham, P. R. Pearson, B. W. Green, and J. M. Kim. 2005. The effects of harvesting and hauling on the blood physiology of adult channel catfish, Ictalurus punctatus. American Fisheries Society, Mississippi Chapter Meeting, February 2005, Philadelphia, Mississippi.

Minchew, C. D., R. V. Beecham, and G. R. Parsons. 2005. Design and calibration of a tilting tunnel respirometer developed to study non-horizontal swimming in fishes. America Fisheries Society Annual Meeting, September 11-15, 2005, Anchorage, Alaska.

Minchew, C. D., R. V. Beecham, P. R. Pearson, B. W. Green, and J. M. Kim. 2007. The effects of harvesting and hauling on the blood physiology and fillet quality of adult channel catfish. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

O'Neal, G. and C. R. Engle. 2007. The effect of lending practices on the financial performance of commercial catfish farms. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Pearson, P. R., B. W. Green, C. D. Minchew, R. V. Beecham, J. M. Kim. 2005. Evaluation of the sock saver aeration unit under commercial channel catfish farming conditions. Aquaculture America 2005, Annual Meeting of the United States Aquaculture Association, January 17-20, 2005, New Orleans, Louisiana.

Pearson, P. R., R. V. Beecham, C. D. Minchew, S. B. Bailey, and M. B. Flanagan. 2007. The LOX calculator for fasted channel catfish. American Society of Agricultural and Biological Engineers Annual International Meeting.

Pugliese, N., D. Heikes and C. Engle. 2006. Confinement system for channel catfish, Ictalurus punctatus, production. Annual Meeting of the World Aquaculture Society, Las Vegas, Nevada

Pugliese, N., D. Heikes and C. Engle. 2007. Evaluation of a confinement system for channel catfish Ictalurus punctatus. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

Pugliese, N., D. Heikes and C. Engle. 2008. Evaluation of a single-batch production scenario for channel catfish Ictalurus punctatus within a confinement system. Annual Meeting of the World Aquaculture Society, Orlando, Florida

Rakocy, J. and J. Hargreaves. 2007. Microbial and water quality dynamics of the UVI biofloc system. Abstracts: Aquaculture 2007, The International Triennial Meeting of the World Aquaculture Society, National Shellfisheries Association, and American Fisheries Society Fish Culture Section, 2007 February 26 March 2, San Antonio, TX, USA, p. 750.

Renwick, K., D. E. Brune, S. Davis, and A. G. Eversole. 2006. Channel catfish fingerling production in the partitioned aquaculture system, Annual Meeting of the U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Las Vegas Nevada.

Renwick, K., D. E. Brune, and A. G. Eversole. 2007. Channel catfish fingerling production in the partitioned aquaculture system. Annual Meeting of the U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, San Antonio, Texas.

Southworth, B. and C. R. Engle. 2007. Producing the right size of catfish: a review of recent production research. Aquaculture 2007, Annual Meeting of the World Aquaculture Society, San Antonio, Texas.

To, S. D. F., C. D. Minchew, E. H. Robinson, J. Doler, Y. Y. Chi, and Said. 2005. Personal in-farm information system

(PIFIS). Precision Agriculture Conference, Info Ag Midsouth, February, 7-9, Tunica, Mississippi.

Torrans, Eugene L. 2008. Recent innovations in aeration. The 2008 Texas Aquaculture Conference, 16-17 January, El Campo, Texas.

Tucker, C. S. 2008. Bacterial bioaugmentation in freshwater aquaculture ponds. The 2008 Texas Aquaculture Conference, 16-17 January, El Campo, Texas.

Tucker, C. S. 2007. Science-based development of cost-effective aquaculture effluent-control strategies. Proceedings of the American Association for the Advancement of Science (AAAS) Annual Meeting, 15-19 February 2007, San Francisco, California. Abstract available online at http://www.abstractsonline.com/viewer/SearchResults.asp

Tucker, C.S. 2009. Environmental sustainability of channel catfish farming. The 238th National Meeting of the American Chemical Society, 16-20 August 2009, Washington, DC.

Tucker, C.S. 2009. Research management. Presentation at the 2009 Mississippi Agricultural and Forestry Supervisory Workshop, 17 July 2009, Starkville, Mississippi.

Tucker, C.S. 2009. Tucker, C. S. 2008. Managing off-flavor in catfish. Presentation for the Alabama Catfish Growers Association, 15 April 2009, Greensboro, Alabama.

Tucker, C. S. and S. K. Kingsbury. 2009. A split-pond aquaculture system for growing catfish. Research and Review: 2009 Catfish Farmers of America Research Symposium, March 3, Natchez, Mississippi.

Wells, T. and D. E. Brune. 2008. High rate catfish fingerling production in the partitioned aquaculture system. Presentation to the South Carolina Department of Natural Resources, Garnett, South Carolina, February 2008.

Zhang, Z, J. Hargreaves, W.H. Wong, and R. Romaire. 2008. The effect of cumulative feed burden (cfb) on the performance of a biofloc system for tilapia. Abstracts: Aquaculture America 2008, United States Aquaculture Society, 2008 February 9-12, Orlando, Florida.

◆ ◆ ◆

FEED FORMULATION AND FEEDING STRATEGIES FOR BAIT AND ORNAMENTAL FISH

Reporting Period
June 1, 2005 - August 31, 2009

Funding Level	Year 1	$102,913
	Year 2	$107,198
	Year 3	$124,952
	Total	$335,063

Participants	University of Arkansas at Pine Bluff (Lead Institution)	Rebecca Lochmann
	University of Arkansas at Pine Bluff (Extension)	Nathan Stone
	Texas A & M University	Delbert Gatlin
	University of Florida	Craig Watson
	University of Georgia	Gary Burtle

Administrative Advisor
Dr. Ron Lacewell
Texas A & M University
College Staion, Texas

PROJECT OBJECTIVES

1. Manipulate diet composition and/or feeding strategy for economical production of "jumbo" golden shiners.

2. Manipulate diet composition and feeding strategy to increase immunocompetence and resistance to stress in bait and ornamental fish during:

    a. Production
    b. Transport and Live Display

3. Determine the relative contribution of natural foods and prepared diets to growth, response to low dissolved oxygen, and other health indices for bait and ornamental fish in different production systems.

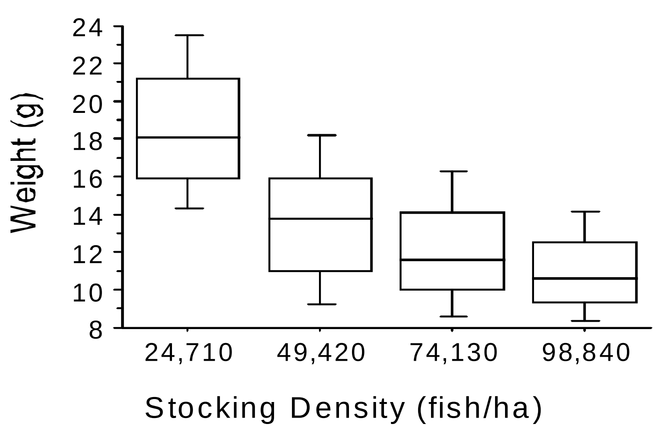
PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Manipulate diet composition and/or feeding strategy for economical production of "jumbo" golden shiners*

University of Arkansas at Pine Bluff. The first objective was to determine an appropriate stocking density for juvenile golden shiners to maximize the production of jumbos (12 g and larger) within a single growing season. This density would then be used for a subsequent study evaluating feeding frequency and diet composition. Golden shiner juveniles (0.5 g) were stocked on July 25 into 12, 0.04-ha fenced and netted earthen ponds at four densities (24,710; 49,420; 74,130; and 98,840/ha) and cultured for 105 days. Fish were fed to satiation once daily with a commercial 42% protein extruded pellet. Ponds were aerated 10 hours nightly using 0.37-kW aerators. Secchi disk visibility was measured every 2 weeks, and total ammonia nitrogen, pH, chlorophyll *a*, dissolved oxygen and zooplankton were determined monthly. Recording thermographs were installed in two ponds and recorded water temperature every 6 hours. Fish were sampled monthly. Ponds were harvested November 7-8. Average fish weight and survival were estimated by weighing and counting five subsamples of at least 25 fish. Weights (g) and lengths (mm) of a sample of at least 50 fish per pond were measured to determine condition and size variation. Remaining fish were bulk-weighed.

Average fish weight declined with increasing stocking density (Figure 1). At the lowest density, 98.4% of the weight at harvest was composed of jumbo fish. Survival ranged from 53 to 87% and was not significantly different among treatments. Gross yield increased with density from 366 to 753 kg/ha and was highly variable among ponds. Net yield of jumbos did not differ among the three higher density treatments. The 74,130/ha (30,000/acre) treatment resulted in an average gross yield of 639 kg/ha, of which 54% by weight was comprised of fish that weighed more than 12 g, and this density was selected for the next trial. Advanced fry were found in six ponds by August, documenting previously undescribed sexual maturity at 3 months

Figure 1. Box plots showing the distribution of fish weights at harvest.



of age in golden shiners. Juveniles stocked into study ponds had been raised from hatchery fry that were obtained on May 11, at 1 to 2 days of age.

Stocking juvenile golden shiners in late July, as was done in this study, results in lower single-season yields of jumbos when compared to direct stocking of hatchery fry at low densities. Previous work showed that direct stocking of fry in early May resulted in about 650 kg/ha of jumbos in a single season. However, the extra production of jumbos must be balanced against other uses for the ponds; juveniles used in this study were produced by stocking fry at 3.7 million/ha for 9 weeks, resulting in yields of about 900 kg/ha.

Results at a glance...

- *Stocking juvenile golden shiners in late July resulted in lower single-season yields of jumbos when compared to direct stocking of hatchery fry at low densities. However, the extra production of jumbos produced by stocking fry must be balanced against other uses for the ponds. Growout diets with no fish meal fed once daily to golden shiners supported yields similar to those obtained with more expensive diets and more frequent feeding.*

A second trial evaluated the effects of diet composition and feeding frequency on the growth and production of golden shiners. Juvenile golden shiners (average weight of 0.46 g) were stocked into 12, 0.04-ha earthen ponds at a rate of 74,100 fish/ha. Fish were fed either once or twice daily with one of two diets (Table 1); a control diet (Diet 1) and an experimental diet (Diet 2), with the intent of matching the performance of fish fed the control diet but at a lower cost. The feed form was an slow-sinking, extruded pellet. Fish were fed at 3% body weight per feeding, adjusted weekly based on an assumed

Table 1. Composition of the diets[1] being tested for producing jumbo golden shiners in a single growing season.

	Amount (g/100g as fed)	
Ingredient	Diet 1 (control)	Diet 2 (no fish meal)
Menhaden fish meal (62%)	26.0	0.0
Poultry by-product meal (60%)	15.0	34.0
Soybean meal (48%)	30.0	40.0
Corn	7.0	5.0
Wheat midds	13.8	12.8
Vitamin C (Stay-C)	0.146	0.146
Choline	0.58	0.58
Vitamin premix	0.4	0.4
Mineral premix	0.1	0.1
Poultry fat	7.0	7.0

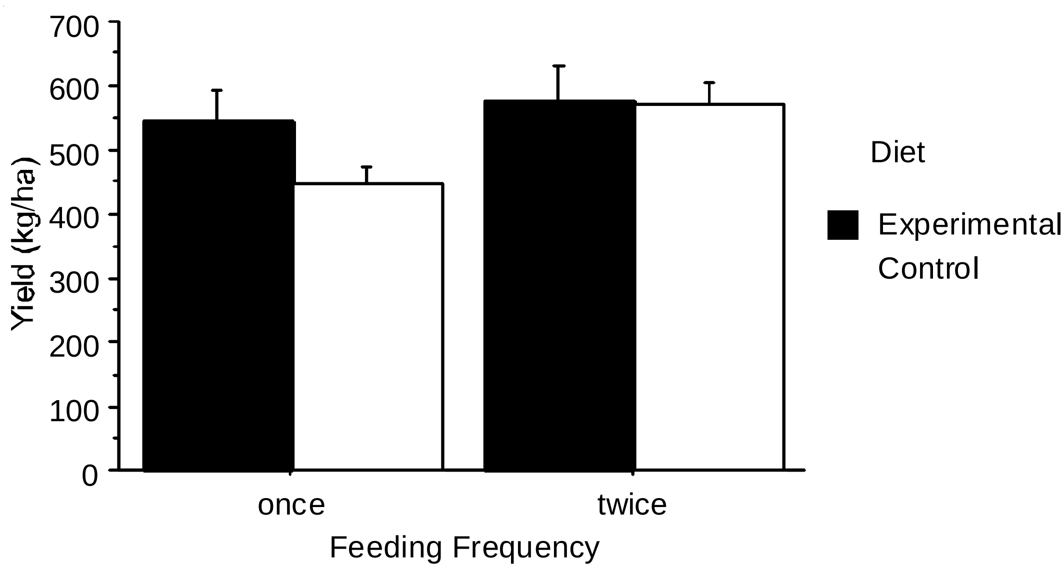
[1] Diets contain approximately 42% total protein and 9-10% lipid by calculation.

feed conversion ratio (FCR) of 1:1 and by sampling every 2 weeks. Ponds were aerated 10 h nightly (2200 – 0800 hours) with 0.37-kW aerators. Secchi disk visibility was measured every 2 weeks, and total ammonia nitrogen, pH, chlorophyll *a*, dissolved oxygen and zooplankton were determined monthly. Ponds were harvested November 19-20 after 80 days.

Average fish weight and survival were estimated by weighing and counting five sub-samples of at least 25 fish. Weights (g) and lengths (mm) of a sample of at least 50 fish per pond were measured to determine condition and size variation. Remaining fish were bulk-weighed.

At harvest, there was no difference in yield (Figure 2), average weight, or survival due to diet or feeding frequency. Yield averaged 535 kg/ha with a standard error of ± 24 kg/ha. Survival ranged from 57 to 80% and mean weight per fish was 10.2 ± 0.4 g. Results showed that feeding a diet with fish meal did not improve yields over a comparable diet formulated with poultry by-products, and that feeding twice a day instead of once a day provided no benefits.

Figure 2. Yield of golden shiners stocked at 74,100/acre for 80-d and fed either once or twice daily at 3% body weight with a 42% crude protein diet with fish meal (Control) or without fish meal (Experimental).



Objective 2. *Manipulate diet composition and feeding strategy to increase immunocompetence and resistance to stress in bait and ornamental fish under simulated commercial conditions.*

Objective 2a. *Production*

Texas A&M University in collaboration with University of Arkansas at Pine Bluff. Three feeding trials were conducted at Texas A&M in recirculating systems with golden shiners to evaluate various potential immunostimulatory diet supplements. These trials were largely inconclusive, possibly due to limited utilization of the practical basal diet formulation that was used to standardize methodology among institutions. Extrusion processing or a different method of particle size reduction may be needed to increase the utilization of these experimental diets by golden shiners.

We also supplemented the work originally planned by developing methodologies to quantitatively measure the immunocompetence and stress responses of baitfish under various conditions. A series of evaluations was conducted to define effective biological endpoints and/or physiological indicators of golden shiner health in response to various stimuli for rapid assessment of fish quality, and development of nutritional, pharmacological or husbandry strategies to enhance production efficiency. Some measurements of immunological and physiological responses have been developed for golden shiner including differential blood leucocyte counts, serum complement and cortisol assays. In Year 1, our group (TAMU) demonstrated that serum lysozyme activity of golden shiner and goldfish is very sensitive to the pH of the bacterial suspension (*Micrococcus lysodeikticus*), compared to hybrid striped bass and channel catfish. The optimal pH for lysozyme assay of golden shiner and goldfish was determined to be 5.9 and 6.0, respectively.

Our research team also found that neutrophil oxidative radical production could be analyzed according to a previously described procedure, but the isolation of head kidney from golden shiner is nearly impossible because that organ is almost invisible.

Our laboratory completed a 10-week feeding trial in a recirculating system with goldfish to evaluate potential immunostimulatory supplements including a commercial dairy/yeast prebiotic (GroBiotic®-A) at either 1 or 2% of diet, the amino acid arginine, and three different nucleotide preparations. After the 10-week feeding period, none of the supplements conferred increased growth, feed efficiency or immunocompetence as measured by oxidative radical production of blood neutrophils. Representative samples of fish fed each diet also were subjected to low dissolved oxygen (DO) stress as originally proposed. However, the goldfish were so tolerant of low DO conditions that we could not kill fish in any treatments even when lowering the DO concentration to below 0.5 mg/L by bubbling nitrogen into the water.

Results at a glance...

- *Prebiotics, immune stimulants, and differences in protein or lipid content of diets had only limited impacts on general performance of golden shiners. However, the prebiotic GroBiotic®-A significantly improved survival of golden shiners exposed to the bacterium that causes columnaris disease. In systems with natural foods (pools or ponds), it was necessary to impose a stressor (crowding) on golden shiners before exposure to bacteria to get a statistically significant increase in survival of fish fed diets with prebiotics. Prophylactic use of the pre-biotic should be economically feasible based on a partial budget analysis of data from the golden shiner pond trial.*

University of Arkansas at Pine Bluff in collaboration with Texas A&M University. In Year 1, a 14-week feeding trial was conducted at the University of Arkansas at Pine Bluff with golden shiner in aquaria to determine whether practical diets supplemented with GroBiotic®-A, extra lipid, or both could improve growth, survival, feed conversion, body composition, or survival upon exposure to low dissolved oxygen. Six diets similar to a commercial diet (30% protein and 9.6 kg energy/gram of protein) were formulated. Two diets contained the same protein components (primarily fish and poultry meals) and differed only in the amount of added lipid (4 and 10% poultry fat).

The diet with 4% fat was the control. Two other diets were similar to diets 1 and 2 except they contained 2% GroBiotic®-A. Two additional diets contained poultry meal in place of fish meal on an estimated digestible protein basis. Twenty-five fish (1.2 ± 0.001 g average weight) were stocked into each of four replicate 110-L tanks per treatment in a flow-through system. Fish were fed twice daily to apparent satiation and group-weighed every 2 weeks to track growth. Weight gain, survival, and feed efficiency are shown in Table 2. Fish fed diets with GroBiotic®-A or no fish meal +4% poultry fat had slightly lower feed conversion ratio (feed offered/fish growth) than fish fed other diets. Statistical analysis of fish weight over time showed some transient differences, but final weight gain did not differ by diet. Post-trial fish were exposed to low dissolved oxygen for 24 hours with no mortality.

Whole-body lipid was analyzed and there were no differences among treatments (Table 2). Because the golden shiners were not large enough to obtain blood for health assays at the end of the feeding trial, a subset of fish was maintained on their experimental diets for 12 more weeks. Alternative complement activity in these larger fish did not differ by diet.

Due to the lack of effect from the low-DO stress test, we performed a columnaris disease challenge on a subset of golden shiners fed the control diet (basal + 4% poultry fat), the basal + 10% poultry fat diet, or the GroBiotic®-A + 10% poultry fat diet. GroBiotic®-A significantly enhanced survival of golden shiner relative to diets with 4 or 10% poultry fat and no GroBiotic®-A.

In Year 3, an 8-week feeding trial was conducted at UAPB with goldfish in aquaria to determine whether practical diets supplemented with GroBiotic®-A, extra lipid, or both could improve growth, survival, feed conversion, body composition, or survival upon exposure to the bacteria that causes columnaris disease. Four diets similar to a commercial diet (30% protein and 9.6 kg energy/gram of protein) were formulated. Two diets contained the same protein components (primarily fish and poultry meals) and differed only in the amount of added lipid (4 and 10% poultry fat). The diet with 4% fat was the control. Two other diets were similar to diets 1 and 2 except they contained 2% GroBiotic®-A.

Table 2. Performance of juvenile golden shiners fed diets containing different concentrations of poultry fat (PF), Grobiotic-A® (GROB), or menhaden fish meal (FM) for 14 weeks[1]

Diet	Mean individual weight gain (g)	Feed conversion	Survival (%)	Whole-body lipid (%)
Basal - 4% PF	1.00±0.06	5.7±0.2b	80.0±2.8	4.1±0.7
GROB - 4% PF	1.15±0.04	5.2±0.2ab	78.0±1.2	4.8±0.7
No FM - 4% PF	1.06±0.05	5.0±0.2a	83.0±3.0	5.3±1.3
Basal - 10% PF	1.06±0.05	5.8±0.2b	88.0±2.3	3.7±0.6
GROB - 10% PF	1.18±0.03	5.0±0.1a	85.0±3.4	6.9±1.2
No FM - 10% PF	1.09±0.09	5.7±0.2b	84.0±2.8	5.7±0.6

[1]Means in columns with different letters are significantly different (P<0.10, Fisher's LSD).

Twenty-five fish (0.57 ± 0.002 g average weight) were stocked into each of four replicate 110-L tanks per treatment in a recirculating system. Fish were fed twice daily to apparent satiation and group-weighed every 2 weeks to track growth. Weight gain, survival, and feed conversion are shown in Table 3. Weight gain, feed conversion and survival of goldfish did not differ among diets. Whole-body lipid was higher in fish fed the 10%-fat diets than in those fed the 4%-fat diets.

After the feeding trial we performed a columnaris disease challenge on goldfish fed each of the diets. Although the goldfish were exposed to higher densities of bacteria than were golden shiners, there were no differences in mortality among goldfish fed different diets. The growth rate of bacteria was so high that it is possible that the nutrients in the broth were depleted, and the bacteria might have been dead at the time of the challenge. To avoid this possibility in the future, fresh broth will be added when the culture is nearing peak optical density for the challenge. Signs of columnaris disease were also seen in some goldfish during the feeding trial. Although infected fish were not used in the challenge, the remaining fish may have been exposed to the bacteria and developed resistance before the challenge.

Table 3. Performance of goldfish in aquaria fed diets containing different concentrations of poultry fat (PF) or GroBiotic®-A (GROB) for 8 weeks. Means were not significantly different (P>0.05, Fisher's LSD).

Diet	Mean individual weight gain (g)	Feed conversion	Survival (%)
Basal - 4% PF	2.13 ± 0.15	1.8 ± 0.1	83.3 ± 4.1
GROB – 4% PF	2.30 ± 0.05	1.7 ± 0.0	85.8 ± 4.2
Basal – 10% PF	2.10 ± 0.09	1.8 ± 0.1	76.7 ± 1.4
GROB – 10% PF	2.31 ± 0.12	1.7 ± 0.1	79.2 ± 4.4

Objective 2b. *Transport and Live Display*

University of Georgia. Whole-cooked soybeans are being compared to soybean meal in diets of golden shiners, feeder goldfish and fathead minnows. Golden shiners were stocked into aquaria in Years 1 and 2 but were subject to excessive mortality within a few days of stocking under a variety of culture conditions. Antibiotics applied to the golden shiners had no significant positive effect on survival. However, increasing salinity of the systems to 3 parts per thousand by addition of artificial sea salts improved survival of the golden shiners.

Subsequent feeding trials with golden shiners in aquaria were improved by the addition of salt to the culture water when using golden shiners from a commercial source or by using golden shiners from a breeding population established on site. Survival of commercial golden shiners was 0% after 14 days in aquaria versus 97% survival for Tifton-reared golden shiners after 56 days in fresh water. When 3,000 mg of sodium chloride was added per liter of water, the commercial golden shiner survival was improved to 85% over 56 days. Fathead minnows obtained from the same commercial source did not show signs of disease and survived at the rate of 95% for 56 days in aquaria in fresh water.

Weight gain for golden shiners fed a complete diet (gain = 0.52 g) or whole-cooked soybeans (gain = 0.57 g) was not statistically different over 56 days when 0.5 gram golden shiners from Tifton ponds were fed to satiation in aquaria. Similarly, weight gain for fathead minnows (1.5 g initial weight) was not significantly different when fed a complete diet (gain = 1.06 g) or whole-cooked soybeans (gain = 1.01 g). Goldfish trials have not been completed.

Pond trials with golden shiners fed roasted full-fat soybean meal show similar growth to golden shiners fed complete diets. Consumption of natural food appeared to provide essential nutrients that are not present in the simple soybean meal diet. Further analyses are in progress.

Economics of feeding for baitfish has changed over the course of this project. Roasted soybeans obtained for $500 per ton in 2006 cost $630 per ton in 2008, FOB Missouri. While 48% protein soybean meal is available for $342 per ton, complete feed costs range from $360 to $640 per ton, depending on quantity and location. At on-the-farm prices of $11 to $12 per bushel, soybean roasting would put feed value between $407 and $444 per ton for whole roasted soybeans. Roasting costs another $25 to $40 per ton. Therefore, baitfish producers, who also raised soybeans, could consider on-the-farm roasting in order to reduce dependence on the feed milling industry during periods of price uncertainty.

Results at a glance...

- *Golden shiners in ponds fed roasted full-fat soybean meal show similar growth to golden shiners fed complete diets. Consumption of natural food appeared to provide essential nutrients that are not present in the simple soybean meal diet. During periods of price uncertainty, baitfish producers who also raise soybeans could consider on-farm roasting to reduce dependence on the feed milling industry.*

Supplemental objective. *Development of methodologies to quantitatively measure the immunocompetence and stress responses of baitfish under various conditions.*

Texas A&M University. An assay of whole-body cortisol has been developed and shown to be quite responsive in measuring stress of shiners subjected to various handling procedures. Samples of golden shiners obtained from a study conducted during year 1 in which fish were subjected to normal harvesting, handling and distribution practices have been analyzed for whole-body cortisol as well as zinc and ascorbic acid as potential indicators of stressful conditions. The whole-body cortisol assay was determined to be a most sensitive measure of stress in golden shiners; whereas, whole-body zinc and ascorbic acid were not readily altered by the various harvesting, grading and transportation stressors.

An additional study examined the effects of four prebiotics, GroBiotic®-A (a mixture of partially autolyzed brewers yeast, dairy ingredient components and dried fermentation products), mannanoligosaccharide (MOS), galactooligosaccharide (GOS), and the fructooligosaccharide (FOS) inulin on digestibility of soybean-meal-based diets by goldfish. A basal diet was formulated so that 50% of the protein was provided by soybean meal and the other 50% was from menhaden fishmeal. Each prebiotic was supplemented to the basal diet at 1% by weight. A diet containing all of its protein from menhaden fish meal also was prepared as a control diet. Chromic oxide was added to the diets at 1% as an inert marker. Each diet was fed to adult goldfish in duplicate 110-L aquaria for a total of 8 weeks. The dried fecal material from each aquarium was pooled over time and analyzed for protein, lipid, organic matter and chromium in order to compute coefficients of apparent digestibility. Results of the study revealed that none of the prebiotics affected apparent digestibility coefficients of the soybean-meal-based diet compared to the basal diet, although the diet supplemented with MOS consistently yielded the lowest values. In addition, goldfish digested the soybean-meal-based diets as well as the control diet. Denaturing gradient gel electrophoresis analysis revealed no differences in microbiota of goldfish fed the various prebiotics. These results are in contrast to those obtained with carnivorous fish species such as the red drum (*Sciaenops ocellatus*) in which the prebiotics increased digestibility coefficients of soybean-meal-based diets and altered GI tract microbiota.

Objective 3. *Determine the relative contribution of natural foods and prepared diets to growth, response to low dissolved oxygen, and other health indices of bait and ornamental fish in different production systems.*

Bait species

Texas A&M University. Based on the positive responses of golden shiners to GroBiotic®-A observed in the first year of this project year at UAPB, two separate feeding trials with goldfish have evaluated the effects of GroBiotic®-A in the presence or absence of natural productivity. Fish have been fed a commercially prepared basal diet and one supplemented with GroBiotic®-A in both a recirculating system containing well water and an outdoor system receiving a continuous supply of pond water. Significantly increased feed efficiency was noted in both feeding trials for goldfish fed GroBiotic®-A when compared to the basal diet. However, no significant differences were noted in regards to percent weight gain or survival over the course of the feeding trials, nor during a controlled disease challenge with *Aeromonas* spp. Goldfish in the presence of natural foods did exhibit significantly greater feed efficiency and survival during the feeding trial, as well as in the disease challenge. Denaturing gradient gel electrophoresis (DGGE) was performed on 16S ribosomal DNA isolated from digesta samples collected from intestinal sections of representative goldfish after each feeding trial to evaluate the relatedness of the GI tract microbiota. These analyses revealed no difference in the GI tract microbiota in the anterior or posterior intestinal sections regardless of diet, unlike previous studies in this laboratory with other species. Additionally, fish fed the diet supplemented with GroBiotic®-A showed a reduced stress response as measured by whole-body cortisol after net confinement.

A feeding trial was conducted with juvenile goldfish initially averaging 3 g per fish in which they were fed diets supplemented with either a dairy/yeast prebiotic

Results at a glance...

- *GroBiotic®-A also enhanced performance (growth, survival, condition index, or feed efficiency) of goldfish in systems with natural foods, and reduced cortisol response of goldfish to crowding stress. Interestingly, no differences in gut microflora were detected in fish fed diets with or without prebiotic, and the mechanism of action still needs to be determined.*

(GroBiotic®-A), a nucleotide product (Ascogen®), or arginine at 1% by weight using gelatin as a carrier to spray the supplements on a practical diet formulation. The fish were reared in the presence or absence of natural productivity, in two culture systems consisting of 38-L aquaria by supplying them with either a continuous flow of pond water or recirculated well water, respectively. The experimental diets were randomly appropriated to three units in each culture system. The goldfish were fed at a fixed percentage of body weight throughout the 10-week trial.

No differences were observed in percent weight gain or survival of fish fed the various treatments at the end of the trial. Feed efficiency was significantly better in goldfish fed the GroBiotic®-A supplemented diet in both culture systems. Blood neutrophil radical production levels as a measure of non-specific immunity were significantly higher in fish reared in the presence of natural productivity regardless of dietary treatment. In addition, during a separate disease trial with *Aeromonas hydrophila*, goldfish fed diets supplemented with either GroBiotic®-A or Ascogen® experienced significantly higher survival rates compared to fish fed the basal diet. Thus, these results indicate disease resistance of goldfish can be improved with dietary supplementation of commercial dairy/yeast prebiotic and nucleotide preparations.

University of Arkansas at Pine Bluff. A 10-week feeding trial with golden shiner in outdoor pools was conducted at the University of Arkansas at Pine Bluff using the same diets described in Objective 2a (see Table 2 for list of diets). Methodological differences from the tank trial included less frequent fish sampling (monthly) to avoid mortalities due to handling stress, and monitoring natural food abundance through Secchi depth and chlorophyll *a* readings. Four hundred (0.46 ±0.002 g in individual mass) fish were randomly stocked into each of four plastic-lined 4.1-m3 pools that were fertilized 1 week before stocking and maintained static during the study. Fish were fed twice daily to apparent satiation and group-weighed every 2 weeks to track growth. Chlorophyll *a* was measured to assess phytoplankton abundance and other water quality parameters were acceptable for golden shiner. Weight gain and feed conversion did not differ by diet (Table 4). There were slight differences in condition factor and survival that were not consistently associated with diet variables (Table 4). Whole-body lipid was significantly higher

Table 4. Performance of golden shiners in pools fed diets containing different concentrations of poultry fat (PF), GroBiotic®-A (GROB), or menhaden fish meal (FM) for 10 weeks. Means in columns with different letters are significantly different (P<0.10, Fisher's LSD).

Diet	Mean individual weight gain (g)	Feed conversion	Condition index	Survival (%)	Whole-body lipid (%)
Basal - 4% PF	1.32 ± 0.13	2.4 ± 0.2	0.85 ± 0.01[c]	99.8 ± 0.2[a]	7.9 ± 0.3[b]
GROB – 4% PF	1.47 ± 0.10	2.6 ± 0.1	0.88 ± 0.01[b]	96.6 ± 1.3[b]	7.8 ± 0.4[b]
No FM – 4% PF	1.56 ± 0.10	2.4 ± 0.1	0.88 ± 0.01[b]	98.9 ± 0.5[a]	8.5 ± 0.3[b]
Basal – 10% PF	1.50 ± 0.21	2.4 ± 0.1	0.91 ± 0.01[a]	99.1 ± 0.7[a]	10.0 ± 0.6[a]
GROB – 10% PF	1.50 ± 0.12	2.5 ± 0.1	0.89 ± 0.01[b]	99.2 ± 0.6[a]	9.6 ± 0.2[a]
No FM – 10% PF	1.43 ± 0.03	2.4 ± 0.1	0.90 ± 0.01[a]	99.6 ± 0.4[a]	9.3 ± 0.3[a]

in fish fed the 10% poultry fat diets compared to those fed the 4% poultry fat diets, regardless of other diet variables.

After harvest, shiners fed the control diet or the diet with 2% GroBiotic®-A were acclimated to indoor tanks and challenged with *Flavobacterium columnare* (trial 1). In trial 2, shiners from the same treatments were subjected to confinement stress or left unmolested, then exposed to *F. columnare*. Mortality (mean ± SE) was not significantly different for the control diet (23.4 ± 3.4%), GroBiotic®-A diet (10.0 ± 3.3%), or GroBiotic®-A diet with stress (16.7 ± 3.4%) treatments. Mortality for the control diet with stress (50.0 ± 3.3%) treatment was significantly greater than the other treatments. This suggests that prebiotic supplementation in golden shiner feeds prior to a stressful event could reduce associated mortality from *F. columnare* significantly compared to control diets.

We evaluated the performance of juvenile golden shiners in ponds fed a control diet or the same formula with 2% GroBiotic®-A. Golden shiner juveniles (0.1 g) were stocked on June 28, 2007 into 10, 0.04-ha fenced and netted earthen ponds at 21.9 kg/ha. Fish were fed to satiation twice daily (4 to 7% body weight) with custom-made 35%-protein diets extruded as 1.5-mm pellets. The diet formulation was similar to a commercial catfish diet. Temperature and dissolved oxygen concentrations were measured daily, Secchi disk visibility and chlorophyll *a* were measured weekly, and total ammonia nitrogen, nitrite, alkalinity, and pH were determined monthly. Ponds were aerated 10 hours nightly using 0.37-kW aerators. Subsamples of fish (100 per pond) were counted and weighed at 2-week intervals to track growth and adjust feed rations. Due to small initial fish size and the relatively low stocking density, growth was very rapid and the study was harvested after 7 weeks to avoid reproduction. At harvest there were no differences in average fish weight, net yield, or feed conversion ratio between treatments (Table 5).

After harvest, 100 fish per pond were moved to indoor tanks for acclimation prior to a bacterial challenge with *Flavobacterium columnare*. Fish were maintained on their respective diets during acclimation and the challenge. Each pond replicate received three experimental treatments: confinement stress for 30 minutes prior to *F. columnare* exposure (stressed); left un-molested prior to F. columnare exposure (un-stressed); or left un-molested and not exposed to *F. columnare* (control). Stress was induced by netting all 24 shiners in a tank and placing them in a small basket suspended within each aquarium. Pre-stress and post-stress fish samples were frozen for subsequent whole-body cortisol analysis to document stress. Confinement stress induced a significantly higher cortisol response compared to unstressed fish, regardless of diet. After the fish were released into the tank they were exposed to a virulent strain (PB02) of *F. columnare* for 18 hours. Mortality was

Table 5. Performance of golden shiners in ponds fed a control diet or a diet with 2% GroBiotic®-A (GROB) for 7 weeks. Means were not significantly different (P>0.10, 1-way ANOVA).

Diet	Average individual weight gain (g)	Net yield (g)	Feed conversion
Control	2.93 ± 0.29	287.0 ± 586.75	1.34 ± 0.08
2% GROB	2.89 ± 0.28	690.3 ± 623.0	1.47 ± 0.10

monitored and recorded for 14 days. Mortality ranged from 0 to 35.0% and was not significantly different for fish in the control or un-stressed treatments fed either the control or 2% GroBiotic®-A diets. The stressed shiners fed the 2% GroBiotic®-A diet also had similar mortality rates compared to control and un-stressed shiners, but the stressed fish that received the control diet had significantly greater mean (± SE) mortality (26.7 ± 4.4%). A partial budget analysis based on the results of the challenge indicate that the increased cost of feed containing 2% GroBiotic®-A would be justified based on increased survival of golden shiners exposed to stress and pathogens.

A 10-week feeding trial with goldfish in pools was conducted using the same diets described in the goldfish aquarium trial at UAPB (see Table 3). Four hundred (0.36 ±0.002 g in individual mass) fish were randomly stocked into each of four plastic-lined, 4.1-m3 pools that were fertilized 1 week before stocking and maintained static for most of the study. Fish were fed twice daily to apparent satiation and subsamples of 100 fish per pool were group-weighed every 2 weeks to track growth. Natural food abundance was monitored through Secchi depth and chlorophyll *a* readings. Other water quality parameters were acceptable for goldfish, except for one instance of high pH (> 9) where fish were showing signs of stress. All pools were flushed with fresh water for 2 hours to restore water quality. At 10 weeks all fish were counted and group-weighed by pool. Fifty individual fish per pool were also euthanized for individual measurements of length and weight to calculate condition index (Fulton's K). These fish were frozen and used for proximate analysis.Whole-body lipid was higher in fish fed the 10%-fat diets than in those fed the 4%-fat diets. Weight gain and condition index of goldfish fed diets with 10% poultry fat, 2% GroBiotic®-A + 4% poultry fat, or 2% GroBiotic®-A + 10% poultry fat were higher than those of fish fed the control diet with 4% poultry fat and no prebiotic (Table 6). Feed conversion and survival did not differ among diets. One hundred goldfish per pool were retained live in the pools where they were fed their experimental diets until they were moved to indoor tanks for acclimation prior to a columnaris challenge. The challenge was conducted in two parts: 1) Fish fed 4% fat diets with or without prebiotic; 2) Fish fed 10% fat diets with or without prebiotic. Within each part, half of the fish in each dietary treatment were stressed by 30 minutes of confinement prior to exposure to columnaris, while the other half were not stressed. Serum cortisol values were higher in confined fish than in unconfined fish. Results were different for fish fed the 4% fat diets or the 10% fat diets. Stressed fish fed the 4% fat

Table 6. Performance of goldfish in pools fed diets containing different concentrations of poultry fat (PF) or GroBiotic®-A (GROB) for 10 weeks. Means in columns with different letters are significantly different (P≤0.05, Fisher's LSD).

Diet	Mean individual weight gain (g)	Feed conversion	Condition index	Survival (%)
Basal - 4% PF	2.26 ± 0.12[b]	1.2 ± 0.03	1.47 ± 0.02[b]	84.1 ± 2.0
GROB – 4% PF	2.54 ± 0.09[a]	1.2 ± 0.04	1.53 ± 0.02[a]	82.9 ± 2.4
Basal – 10% PF	2.74 ± 0.07[a]	1.2 ± 0.03	1.58 ± 0.02[a]	85.0 ± 1.5
GROB – 10% PF	2.56 ± 0.07[a]	1.3 ± 0.02	1.54 ± 0.02[a]	86.9 ± 2.6

diet with prebiotic had lower mortality than those fed the same diet without prebiotic. However, stressed fish fed the 10% fat diets had higher mortality than unstressed fish, regardless of prebiotic inclusion. The basis for the protective effect of the prebiotic in 4%-fat diets but not in the 10%-fat diets is unknown.

University of Georgia. Pond feeding trials are in progress using fathead minnows. At that time, transport hardiness will be evaluated.

Ornamental species

University of Florida. During this project we submitted five species of fish (*Brachydanio rerio*, zebra danios; *Xiphophorus helleri*, swordtails; *Hypostomus* sp., common plecostomus; *Cichlasoma meeki*, firemouth cichlid; and *Moenkhausia sanctaefilomenae*, red-eye tetra) to the treatments outlined in the original proposal. The original objective was to determine the relative contributions to ornamental fish growth of direct consumption of manufactured feed and natural foods produced as an indirect result of feeding. At the time the proposal was submitted there was at least one large feed supplier selling farmers unprocessed meal diets, but at a relatively expensive cost, and this work was designed to determine whether use of a processed (i.e., pelleted and reground) diet would provide better growth and survival. Two fertilization regimes were also added to the tests to determine the ability of these species to utilize primary and secondary productivity. Each trial consisted of 6 replicated ponds of each species, with four treatments: 1) cottonseed meal; 2) liquid fertilizer; 3) unprocessed, 33%-protein meal-type diet; and 4) processed, 33%-protein diet. Ponds were stocked at rates consistent with industry standards, and trials were each conducted for 12 weeks. A similar tank trial was conducted with each species to compare growth and survival using the two diets. Ten replicate tanks of fish were fed each diet for 12 weeks and growth and survival measured and compared. Other measurements included water quality (ammonia, nitrite, pH, temperature, and dissolved oxygen), and weekly chlorophyll *a* samples from pond studies.

A "low dissolved oxygen" stress test was conducted on three of the five species, but was discontinued as it showed no significant measurement of the fish's ability to handle stress due to deprivation of dissolved oxygen.

There were significant differences in the growth and survival of zebra danios produced in ponds receiving treatments of liquid fertilizer, cottonseed meal, an unprocessed meal diet, and a processed diet. Growth on the processed diet was best, followed by unprocessed diet, cottonseed meal, and liquid fertilizer. Although growth was best with the addition of processed diets or organic materials, liquid fertilizer alone produced a good number of market-sized fish with minimal costs. The economics of each level of input need further analysis. Zebra danios fed a processed diet in tanks also outperformed fish fed an unprocessed diet.

Survival of swordtails in all pond studies was greater than 100% due to reproduction in the pond during the 12 weeks. Overall survival was based on number of fish at final harvest with the processed

Results at a glance...

- *Zebra danios, swordtails, plecostomus, firemouth meeki cichlids, and red-eye tetras performed similarly on processed or unprocessed diets in ponds, while results were generally less favorable for liquid fertilizer or cottonseed meal treatments. In some species, a large number of fish could be produced with fertilizer alone, but fish size was reduced. Except for zebrafish, these species also performed similarly on processed and unprocessed diets in aquaria.*

diet treatment being highest followed in order by the unprocessed diet, liquid fertilizer and cottonseed meal treatments. Overall weight of fish produced differed among treatments. There was an increase in overall weight of fish produced in each treatment, with the processed diet providing the highest overall weight, followed by the unprocessed diet, cottonseed meal, and liquid fertilizer. No significant difference in production were seen in tanks studies for swordtails.

Yields of plecostomus in pond studies also differed among treatments, with yields decreasing in the following order: unprocessed diets > processed diets > cottonseed meal > liquid fertilizer. Survival varied dramatically, with survival in the liquid fertilizer treatment being only 10%, compared to 65% survival for the unprocessed diet. No significant differences in growth or survival between the unprocessed and processed diet treatments were found in the tank study.

Highest yield of firemouth meeki cichlids in ponds was obtained on the processed diet treatment, followed in order by the unprocessed diet, liquid fertilizer, and cottonseed meal. Firemouth meeki cichlids readily spawn in ponds, and reproduction and survival of offspring was best in the liquid-fertilized ponds, but fish size was significantly smaller than in the ponds receiving either diet. There was no significant difference in growth or survival of Firemouth meeki cichlids fed either diet in the tank study.

The processed diet treatment provided highest yield of red-eye tetras in ponds, followed in order by the unprocessed diet, cottonseed meal, and liquid fertilizer treatments. However, the total weight of fish was less with the unprocessed diet than with cottonseed meal, and the total number of fish was greatest with cottonseed meal, followed by processed diets, unprocessed diets, and liquid fertilizer. Tank studies for red-eye tetras showed no significant difference in growth or survival between the two diets.

Chlorophyll *a* values were consistent throughout the study for all species. A significant difference in primary productivity (based on chlorophyll *a*) was also observed, consistent with anticipated results (i.e. fertilized ponds were high in primary productivity, with unprocessed and processed diet treatments showing a lower level of chlorophyll *a*.)

The small size of most ornamental species allows them to utilize primary and secondary productivity, but the impact of this source of nutrition alone was unknown for most species. This project demonstrated that pond fertilization alone can produce a significant number of fish, and at a relatively low cost, but the size of fish grown on fertilizer alone is significantly smaller than for fed fish. There also was a general trend toward increasing growth and survival in ponds with processing of the diet, but not for all species (e.g., plecostomus fed an unprocessed diet had a 13% increase in survival). Selection of type of "fertilization" from an organic fertilizer such as cottonseed meal to use of an inorganic fertilizer also affected yield, but again there was variation in this trend between species. Survival and total yield of firemouth meeki cichlid was dramatically increased in ponds with inorganic fertilizer relative to ponds fertilized with cottonseed meal. Chlorophyll *a* levels and water quality parameters were consistent with expectations, showing higher productivity in the pond water when fertilization was used rather that a diet.

Several issues related to the overall value and impact of this study should be addressed in future work. All fish except the firemouth meeki cichlids and the danios were procured for the study from local producers. Red-eye tetras were received at a very small size from a local hatchery, and their counting methodology was obviously flawed. We attempted to stock 7,500 fry per pond, and physically counted over 30,000 fish in some ponds at harvest. Future studies should not rely on external parties counting fish, and there is an obvious need to assist farms with how they are enumerating their inventories while stocking.

WORK PLANNED

UAPB and Texas A&M University (TAMU) are doing supplemental collaborative work on the effects of prebiotics in baitfish species.

IMPACTS

The overall goal of this project is to develop diets, feeding practices, and production strategies that enhance stress resistance and prolong survival of bait and ornamental fishes. Production diets with no fish meal fed once daily to golden shiners support yields similar to those obtained with more expensive diets and more frequent feeding. The use of a dairy/yeast prebiotic has shown consistently positive results in baitfish and the cost should be offset by improved survival under production conditions. The prebiotic was effective in golden shiners in ponds even at a low stocking density, where natural foods typically have a greater impact on performance. Similarly, the prebiotic improved survival of goldfish raised in outdoor pools with 4%-fat diets and natural foods, followed by stress and exposure to columnaris. The economics of these feed additives look promising, but need further verification due to the small scale of the baitfish industry.

In addition to the positive effects of a commercial dairy/yeast prebiotic on disease resistance of golden shiners observed by co-investigators on this project, this prebiotic improved stress resistance of goldfish based on a reduction in whole-body cortisol after net confinement. Thus, this prebiotic appears to have considerable potential as a feed additive to protect baitfish from stressors and diseases commonly encountered in production.

Whole roasted soybean, when ground into a meal, can produce good growth in golden shiners, fathead minnows, and goldfish, provided they are in ponds with natural food available. Soybean economics should be considered before using whole roasted soybean meal. However, this product could allow on-the-farm production of baitfish feeds.

Performance of golden shiner in ponds fed full-fat soybean meal or a nutritionally complete diet was comparable. Therefore, full-fat soybean meal can be used to reduce production costs when complete diets are more costly. Baitfish producers who also produce soybeans may realize additional profits by roasting the soybeans on-farm.

With ornamental species, pond fertilization alone produced a significant number of fish, and at a relatively low cost, but the size of these fish was significantly smaller than when feeds were used. Several ornamental fish producers have altered their stocking densities and feeding regimes based on the findings of the pond studies in this project. Overall, there was a general improvement in growth and survival of ornamental species using a processed diet. Perhaps most importantly, there were no advantages to using the expensive, unprocessed meal that was used previously by the ornamental fish industry, which should discourage farms from renewing a market for these diets.

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED

Publications

Li, P. B. Ray, D. M. Gatlin III, T. Sink, R. Chen and R. Lochmann. 2009. Effect of handling and transport on cortisol response and nutrient mobilization of golden shiner Notemigonus crysoleucas. Journal of the World Aquaculture Society 40:803-809.

Lochmann, R.T., T.D. Sink, and H. Phillips. 2009. Effects of dietary lipid concentration, a dairy/yeast prebiotic, and fish and non-fish protein sources on growth, survival, and non-specific immune response of golden shiner, Notemigonus crysoleucas, in indoor tanks and outdoor pools. North American Journal of Aquaculture 71:16-23.

Lochmann, R.T., T. Sink, N. Kinsey, and E. Marecaux. 2010. Effects of a dairy/yeast prebiotic on performance of golden shiners in ponds. North American Journal of Aquaculture, in press.

Savolainen, L. C. and D.M. Gatlin III. 2009. Evaluation of dairy/yeast prebiotic supplementation in the diet of juvenile common goldfish *(Carassius auratus)* in the presence or absence of phytoplankton/zooplankton. Journal of Aquatic Animal Health 21:156-163.

Sink, T.D., S. Kumaran, and R.T. Lochmann. 2007. Development of a whole-body cortisol extraction procedure for determination of stress in golden shiners, Notemigonus crysoleucas. Fish Physiology and Biochemistry 33:189-193.

Sink, T.D., R.T. Lochmann, A.E. Goodwin, and E. Marecaux. 2007. Mortality rates in golden shiner, Notemigonus crysoleucas, fed high-fat diets with or without a dairy/yeast prebiotic prior to challenge with Flavobacterium columnare. North American Journal of Aquaculture 69:305-308.

Sink, T.D., and R.T. Lochmann. 2008. Preliminary observations of mortality reduction in stressed, Flavobacterium columnare, challenged golden shiners after treatment with a dairy-yeast prebiotic. North American Journal of Aquaculture 70:192–194.

Theses and Dissertations

Raggi, T. (2009) Prebiotics have limited effects on nutrient digestibility of a soybean meal-based diet by goldfish *Carassius auratus*. Masters Thesis, Texas A&M University.

Manuscripts in preparation

Li, P., R.T. Lochmann, and D.M. Gatlin, III. Determination of optimal pH for measurement of serum lysozyme activities of various warm water fishes. Fish and Shellfish Immunology.

Lochmann, R., T.D. Sink, H. Phillips, and R. Chen. The effects of a dairy/yeast prebiotic on growth and health of goldfish in indoor tanks and outdoor pools. North American Journal of Aquaculture.

Savolainen, L. C., T. Raggi and D. M. Gatlin III (2009) Evaluation of arginine, nucleotides and a dairy/yeast prebiotic on resistance of juvenile common goldfish (*Carassius auratus*) to *Aeromonas hydrophila*. Journal of the World Aquaculture Society.

Presentations

Chen, R., H. Phillips, and R. Lochmann. 2009. Effects of standard and high-fat diets with or without a dairy/yeast prebiotic on performance of goldfish *Carassius auratus* in aquaria. Aquaculture America 2009, February 16-18, Seattle, Washington.

Gatlin, D.M., III. 2008. Review of prebiotic research with fish and shrimp. Texas Aquaculture Association Conference, January 16-18. El Campo, Texas.

Gatlin, D. M., III, P. Li, B. Ray, R. Chen, T. Sink, and R.T. Lochmann. 2007. Review of immune and stress responses of golden shiner, Notemigonus crysoleucas. Aquaculture America 2007, February 26-March 3, San Antonio, Texas.

Gatlin, D. M., III, P. Li, X. Wang, G. S. Burr, F. Castille A. L. Lawrence and A. Buentello. 2007. Potential application of prebiotics in fish and shrimp culture. Thirty-first Fish Feed and Nutrition Workshop, May 16-17, Auburn, Alabama.

Li, P., T. Sink, B. Ray, R. Chen, R. Lochmann and D. M. Gatlin III. 2008. Effect of handling and transport on cortisol response and nutrient mobilization of golden shiner Notemigonus crysoleucas. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Lochmann, R.T., T. Sink, N. Kinsey, and E. Marecaux. 2008. Effects of a dietary prebiotic on performance of golden shiners in ponds. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Lochmann, R., T. Sink, and H. Phillips. 2008. Effects of a dairy-yeast prebiotic on performance of golden shiner in tanks, pools and ponds. Arkansas Bait and Ornamental Fish Grower's Association Meeting, February 7, Lonoke, Arkansas.

Lochmann, R., T. Sink, H. Phillips, and F. Bearden. 2008. Effects of a prebiotic, lipid concentration, and protein source on performance of golden shiner (Notemigonus crysoleucas) in outdoor pools. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Lochmann, R.T., N. Stone, A. Kachowski, and A. Gannam. 2008. Effects of diets with and without fish meal and feeding frequency on the growth of juvenile golden shiners. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Lochmann, R. 2007. Overview of shiner prebiotic studies. Thirty-first Fish Feed and Nutrition Workshop, May 16-17, Auburn, Alabama.

Lochmann, R., T. Sink, H. Phillips, P. Li, and D.M. Gatlin, III. 2007. Effects of a feed additive, lipid concentration, and protein source on performance of golden shiner (*Notemigonus crysoleucas*). Aquaculture America 2007, February 26 - March 3, San Antonio, Texas.

Lochmann, R., N. Stone, and A. Kachowski. 2007. Stocking rates for juvenile golden shiners to maximize single-season production of jumbo (>12 g) fish. Aquaculture America 2007, February 26 - March 3, San Antonio, Texas.

Lochmann, R.T., T.D. Sink, H. Phillips, P. Li, and D.M. Gatlin, III. 2006. Effects of a feed additive, lipid concentration, and protein source on performance of golden shiner in tanks. UAPB Aquaculture/Fisheries Field Day, October 5, Pine Bluff, Arkansas.

Phillips, H., N. Kinsey, and R. Lochmann. 2009. Effects of standard and high-fat diets with or without a dairy/yeast prebiotic on performance of goldfish *Carassius auratus* in outdoor pools. Aquaculture America 2009, February 16-18, Seattle, Washington.

Raggi, T., G. Burr, B. Ray, A. Buentello and D. Gatlin III. 2009. Effects of prebiotics on nutrient digestibility of a soybean meal-based diet by goldfish *Carassius auratus* Aquaculture America 2009, February 16-18, Seattle, Washington.

Savolainen, L. C. and D. M. Gatlin III. 2009. Evaluation of the prebiotic Grobiotic®-A in the diet of juvenile common goldfish (*Carassius auratus*) in the presence or absence of natural productivity. Aquaculture America 2009, February 16-18, Seattle, Washington.

Savolainen, L.C. and D.M. Gatlin III. 2008. Evaluation of the prebiotic GroBiotic®-A in the diet of juvenile common goldfish (Carassius auratus) in the presence or absence of natural productivity. Texas A&M Student Research Week, Texas A&M University, College Station, Texas.

Sink, T.D., R.T. Lochmann, and S. Kumaran. 2008. Development of a whole-body cortisol extraction procedure for determination of stress in golden shiners Notemigonus crysoleucas. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Sink, T., R. T. Lochmann, A. E. Goodwin, and E. Marecaux. 2007. Mortality rates in golden shiners, Notemigonus crysoleucas, fed diets high in fat and the prebiotic GroBiotic®-A prior to challenge with Flavobacterium columnare.Aquaculture America 2007, February 26 - March 3, San Antonio, Texas.

Sink, T.D., R. T. Lochmann, A. E. Goodwin, and E. Marecaux. 2006. Mortality rates in golden shiners, Notemigonus crysoleucas, fed diets high in fat and the prebiotic GroBiotic®-A prior to challenge with Flavobacterium columnare. Poster presentation, UAPB Aquaculture/Fisheries Field Day, October 5, Pine Bluff, Arkansas.

Stone, N., A. Kachowski, and R. Lochmann. 2006. Evaluation of low stocking rates for juvenile golden shiners to maximize single-season production of jumbo fish. Poster presentation, UAPB Aquaculture/Fisheries Field Day, October 5, Pine Bluff, Arkansas.

Watson, C. 2008. Diet and feeding strategies for ornamental fish; feed the pond or feed the fish, year 2. Aquaculture America 2008, February 9-12, Lake Buena Vista, Florida.

Watson, C. 2007. Growth and survival of ornamental fish based on pond fertilization and feeding. Aquaculture America 2007, February 26 - March 3, San Antonio, Texas.

◆ ◆ ◆

DEVELOPMENT AND EVALUATION OF POND INVENTORY METHODS

Reporting Period
May 1, 2007 - August 31, 2009

Funding Level	Year 1	$157,818
	Year 2	137,423
	Total	$295,241

Participants	Louisiana State University	Ray McClain, Robert Romaire
	Mississippi State University	Doug Minchew
	University of Arkansas at Pine Bluff	David Heikes, Steeve Pomerleau, Yong-Woo Lee
	University of Florida	Craig Watson
	University of Mississippi	James Chambers, John Heffington

Administrative Advisor
Dr. Jacqueline McCray
University of Arkansas at Pine Bluff
Pine Bluff, Arkansas

PROJECT OBJECTIVES

1. Determine the most accurate and reliable methodologies for estimating ornamental fish density and size distribution in commercial ponds.

2. Determine the most accurate and reliable methodologies for estimating crawfish density and size distribution in experimental ponds and develop a means to estimate annual yield and harvest size from sampling methodologies.

3. Modify the Aquascanner Catfish SONAR system to size individual catfish collected from commercial catfish ponds.

4. Develop and evaluate several down-looking and low frequency side-scan sonar technologies to determine numbers of channel catfish in ponds.

5. Develop and evaluate a catfish trawl and portable computing technologiesto estimate size distribution and biomass in catfish production ponds.

ANTICIPATED BENEFITS

Maintaining accurate inventory records in large earthen-pond aquaculture systems has always been problematic. Accurate biomass, headcount and size distribution information is critical for production management, business planning, accounting, and operation financing. This project will enhance current pond inventory methodologies and will foster the development of novel techniques and/or equipment to objectively assess biomass, headcount and size distribution information in aquatic production systems. These technologies will help to improve the long-term sustainability of aquaculture production in the southeast.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Determine the most accurate and reliable methodologies for estimating ornamental fish density and size distribution in commercial ponds.*

University of Florida. Ornamental fish production varies from extremely intensive indoor recirculating systems to extensive outdoor earthen ponds. Regardless of the culture method, ornamental fish farmers are dependant upon producing their own fry. The farmers that choose egg-layer species generally have much more control over their production then do their live-bearer counterparts. This is due to the fact that production numbers of egg-layers can easily be controlled by varying the number of breeding pairs, whereas most live-bearers are produced by pond spawning. The only control of a typical live-bearer facility occurs during the initial introduction of broodstock as well as in subsequent culling necessary during the production cycle, which can be as long as 3 years.

Traditional methods for estimating stocking, growout, and harvesting (final) inventories are primarily based on personal knowledge of number of fry per spawn (egg-layers), general productivity of broodfish (live-bearers), generalized observations during growout, and historical success of individual ponds. Very little, if any, record keeping is employed in these methods. Producers often will simply estimate the number of fish stocked, and maintain a running, mental estimate of how many fish are in each pond. Often there is not even a written record of what ultimately is sold from each pond. These methods make planning production, improving survival, and increasing growth very difficult. In this project, these traditional methods will be compared to actual counts on commercial egg layer and live bearer facilities as well as experimental ponds located at the University of Florida/IFAS Tropical Aquaculture Laboratory (TAL).

Improved methods will include physical counts of fecundity of female broodfish, volumetric estimates of number of fry at stocking, sub-sampling of inventory three times through growout using partial seine techniques, and physical counts of fish at harvest. Both methods (traditional and improved) will be documented and monitored on a simple Excel spreadsheet. Costs also will be estimated for each method based on man-hour requirements, and benefits will be based on the accuracy of each method. Another anticipated positive effect is the use of improved inventory methods to allow for more efficient production planning and increases in total production per pond.

Our first major objective was to increase the accuracy and reliability of methods for determining ornamental fish density and size distribution in commercial ponds and develop a simple computer based record keeping spreadsheet. For the initial portion of the project a very experienced, well-organized ornamental egg-layer producer was chosen. This producer did not represent the majority but rather the minority, reflected by his record keeping. The fish used was a Serpae tetra (*Hyphessobrychon serpae*), commonly know as a Red Minor. All fish used were in excellent health and very well conditioned. The spawning room (climate controlled) was prepared with 500 individual 7.6-L (2-gallon) spawning tanks, each containing roughly 5.7 L (1.5 gallons) of spawning water. The tanks were then equipped with an air line and benthic spawning media. Once prepared each tank received a female, followed later by a male, and then was left alone for 48 hours. On the second day the tanks were inspected for eggs and the breeders removed. On the third day the spawning media was removed as the fry were now free swimming. On the fourth day the tanks were numbered and fifty tanks were randomly chosen (Figure 1). The producer was not told which tanks were chosen. After tanks were labeled, the producer was asked to estimate the number of fry in each of the 500 spawning tanks three times. He did this by holding the spawning tanks up to the light one by one and qualitatively estimated the number of fry (Figure 2). The fry were then equally distributed into 28 larval rearing vats, except for the 50 tanks identified

Figure 1. One rack of 2-gallon spawning tanks.

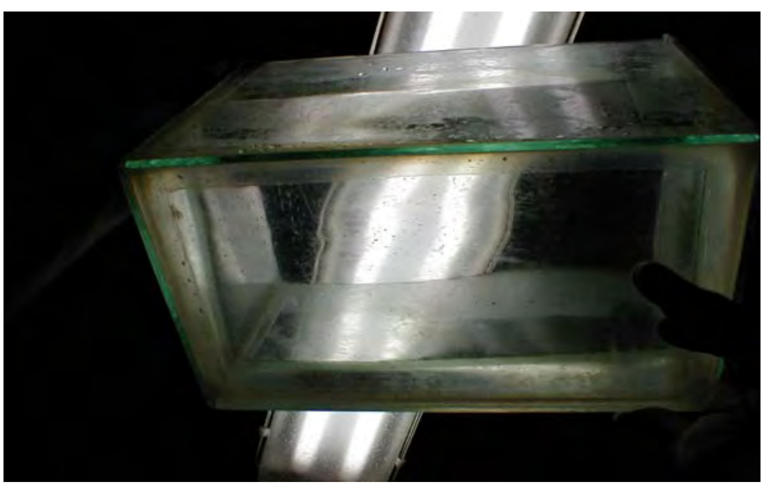


Figure 2. Spawning tank held overhead to the light for fry estimation.

above, which were used to generate our exact count. This was done by first euthanizing the fry in each spawning tank and transferring the fry from one spawning tank at a time into a clean, white bucket. Fry were counted by carefully aspirating each fry into a 1-ml pipette. The actual total was then compared to the producer's estimates. The fry from each remaining tank were then reared for 3 weeks before being stocked into two properly prepared 3-m (6 feet) deep, 0.02-ha (0.04-acre) growout ponds. The producer was again asked to estimate the number of juvenile fish going into each of the two growout ponds. He did this by reviewing his notes regarding his estimates of fry per vat as well as a close inspection of each individual vat. He then selected 10 vats for each pond. In order to generate our count we randomly selected eight vats and swim-counted each juvenile. This was done by first netting all the juveniles in the vat using a large vat net, then dipping into that vat net with a small handnet.

Each dip of the hand net caught roughly 100 juveniles which were then allowed to swim one at a time out of the hand net into a large Styrofoam box. After counting the contents of each dip the juveniles were returned to a separate large vat net within a new vat. This process was repeated until every juvenile was individually counted in each of the eight selected vats. Because the juveniles involved in our count were severely stressed they were ultimately stocked into a separate pond and did not factor into the later results. The actual total was then compared to the producer's estimates.

The two growout ponds were visually monitored twice daily by the producer during daily feedings and weekly for the duration of the 4-month growout cycle. Actual harvest numbers were supplied by the producer which reflected exact sales receipts.

Numbers of Red Minor fry that were in each spawning tank were grossly underestimated by the producer. Actual total count for the 50 tanks was 27,883 fish. The three estimates by the producer were 7,048, 7,265, and 6,615 fish. In other words, the actual counts were 3.8 to 4.2 times higher than the estimates of the producer. In individual tanks, the magnitude of the difference between actual counts and the producer's estimates increased dramatically as the total number of fish in the tank increased. For example, in one tank, the producer's estimates averaged 300 fish although the tank actually contained 1,479 fish, or almost 5 times estimated number.

The producer's estimate of the amount of Red Minor juveniles stocked into each pond was very close to actual counts, and exceeded the actual estimate only by 9.78%. The actual harvest totals for the two ponds were 54.4% and 69.4% of the estimates based on actual counts.

Some early attempts at increasing larval nutrition in order to increase the survival from fry to juvenile have proven favorable. The harvest results for both ponds were considered low for this facility, although harvest values of 50% or more are commonly accepted in the industry. It was observed and recorded that during the 4-month grow out cycle both ponds of Red Minor were treated for external parasites and were also plagued by wading birds.

Attempts to enumerate live bearer inventories on two participating commercial facilities were discontinued due to catastrophic losses occurring on both farms during both summers during this study. Using data collected at the Tropical Aquaculture Laboratory we were able to evaluate expected production of swordtails in open ponds. Based on previous data from tank studies, predicted production was 1.32 fry/female/day. Five ponds were each stocked with 200 female and 50 male swordtails, and fed a standard diet for 12 weeks, the typical time needed for swordtails to reach market size. Predicted inventory at harvest was 22,426 total fish [(200 females)(1.32 fry per female per day)(84 days) + 250 original broodstock]. After ponds were harvested and all fish counted, resulting average total inventory was 20,292 fish, or 90% of the predicted harvest. Based on this finding farms can anticipate an average production of 1.18 fry/female/day in open ponds after 12 weeks of production for swordtails.

Results at a glance...

- *A simple estimate of number of fry per female per day can be used to estimate the inventory of live bearers per pond over a 12 week production cycle.*

For the final portion of the project, we cooperated with an experienced producer of egg layer ornamental fish. The fish used was a three-spot gourami (*Trichogaster trichopterus*), of the variety known as the Blue Gourami. The climate-controlled spawning room was prepared with 60 individual 10-gallon spawning tanks, each containing roughly 3.5 gallons of water. Once the fry were free swimming, tanks were numbered and six tanks were randomly chosen. The producer was asked to estimate the number of fry in each of the 60 spawning tanks three times by holding a light under each spawning tank and estimating the total number of fry. Fry were then equally distributed into two, 30-gallon rubber tubs (27 tanks per tub) with the exception of the six tanks used above. The producer made a visual estimate of the number of fry per tub.

Fish in the six tanks were euthanized and hand-counted using a 1-mL pipette. This actual total was then compared to the producer's estimates. Numbers of Blue Gourami fry in each spawning tank were grossly underestimated by the producer. Actual counts ranged between 8.2 to 8.5 times higher than the estimates made by the producer.

A simple subsampling method was employed to enumerate the fry in the larger tubs. Each tub was filled with 30 liters of water. The water was gently mixed to equally distribute fry in the water. Three individual 50-mL samples were taken from each tub. Fish in each 50-mL sample were then counted and recorded. These subsample estimates were then compared to the producer's visual tub estimates. Again, actual numbers of Blue Gourami estimated by subsampling were much higher than the producer's estimates. One tub was under-estimated by approximately 3-fold and the other by 2.5-fold.

Fry were then stocked into two growout ponds which were monitored twice daily by the producer during daily feedings. Harvest data will be based on sales receipts (not available at this time).

Objective 2. *Determine the most accurate and reliable methodologies for estimating crawfish density and size distribution in experimental ponds and develop a means to estimate annual yield and harvest size from sampling methodologies.*

Louisiana State University Agricultural Center. Crawfish farming in Louisiana does not rely on a hatchery component for populating grow-out ponds, unlike many aquaculture enterprises around the world. Rather, dependence is upon indigenous and/or supplemented broodstock to reproduce naturally in subsurface burrows as crawfish in the region have evolved to do. Without the reliance on natural reproduction, crawfish farming would probably be non-profitable. While the advantages of natural reproduction are great, there are several drawbacks. Reliance on natural reproduction subjects the grower to great variations in yield and harvest size due to large natural variations in adult survival and reproductive success from year to year and pond to pond. Not only are yield and size variations problematic due to variations in recruitment patterns, but these problems are exacerbated by a lack of predictability and a reliable means of assessing pond inventory. Currently, there is no reliable means of accurately determining the success or failure of young-of-the-year recruitment. Without a means of determining population density and structure prior to initiation of harvesting, economic and business planning and implementation of corrective measures are not viable tools for the producer.

Natural, staggered recruitment and heavily vegetated ponds have limited the development of accurate population assessment techniques in crawfish ponds. Previous efforts to establish population sampling in crawfish ponds as a predictor of yield outcomes, though imprecise, were undertaken mainly in crawfish monocropping systems and were accomplished without the knowledge of actual pond densities. Largely unsuccessful, producers do not routinely attempt precise assessments of population density or structure. Therefore, this project attempted, for the first time, to eliminate natural recruitment and instead accomplish the tasks of populating ponds with stocking of hatchlings at known numbers. This was done so that systematic sampling efforts could be employed with the intent of establishing some kind of relationship between sampling (with different gear) and known populations, and furthermore, to determine if harvest results could be relatively associated with sampling outcomes.

A rice crop was planted and harvested during the summers of 2006 and 2007 in 12, 0.4-ha (1-acre) experimental plots each year at the LSU AgCenter's Rice Research Station. The rice stubble was managed for regrowth according to typical rice-crawfish rotational practices in the region. Although the fields (ponds) were not stocked with crawfish broodstock as is customary, the fields were flooded in late September and Karate™ (a pyrethroid insecticide) was applied at the rate of 4 ounces/acre to minimize natural recruitment from indigenous crawfish that may have entered the plots from an adjacent rice field. After about a week, the ponds were completely drained and reflooded 3 days later with fresh water for the duration of the crawfish production cycle. Crawfish population was accomplished by stocking of hatchlings, spawned under laboratory conditions, at known densities and predetermined timings.

Five stocking treatment combinations were investigated in season 1 and six were examined in season 2. Factors consisted of a low stocking rate with one age class (Low-1), low stocking rate with four age classes (Low-4), high stocking rate with a single age class (High-1), high stocking rate with four age classes (High-4), and no stocking of hatchlings (0-Stocking). The additional treatment added in season 2 consisted of a single age class at low density stocked late in the season. Crawfish densities of approximately 2.5 (2.3 to 3) crawfish/m^2 were considered low, and densities of about 6.5 (5.9 to 7) crawfish/m^2 were considered high for this study. Timing of the multiple stockings occurred every 2 weeks from 16 October to 28 November in season 1 and from 2 October to 13 November in season 2. The "Late-low" stocking occurred on 11 December in season 2.

Population sampling prior to initiation of harvests consisted of employing four sampling gear: large mesh traps, consisting of standard 0.75-inch square mesh pyramid traps, small mesh traps, consisting of common 0.25-inch wire mesh minnow traps with 1.25-inch funnel openings at each end, long handle dip nets (3-mm mesh), and specially constructed drop sampling devices (0.5 m2 surface area). The drop sampler consisted of a metal cylinder that was rigged to slide up and down on three legs with a trigger that allowed the unit to be "set" in the up position with 15 m (50 feet) of rope, whereby the unit could be placed in the pond some distance and triggered from the levee to prevent disturbing of crawfish during sampling (Figure 3). When "dropped," the sampler formed an enclosure entrapping any crawfish that were captured within the interior of the cylinder. Water was pumped out and crawfish counted and sized.

Sampling was conducted during six weekly periods: 11-15 December, 8-12 January, 22-26 January, 5-9 February, 19-23 February, and 5-9 March in season 1 and 3-7 December, 17-21 December, 7-11 January, 21-25 January, 4-8 February, and 18-22 February in season 2. The large- and small-mesh traps were employed with and without bait and were placed both around the pond edge and away from the edge within the interior of the pond (with duplicate traps per pond per location per bait regime). Dip net sweeps were accomplished both around the pond edge and within the pond interior (with 10 random sweeps per pond per location). The drop samplers were operated in the morning (approximately 0830 hours) and afternoon (approximately 1600 hours). Traps and dip net sweeps were accomplished in duplicate ponds of each treatment, while drop samplers were not duplicated by treatment, occurring in only one replicate of each treatment. Crawfish catch, total and by size category, were noted for each sampling effort (Figure 4).

A total of 502 spawns (over 150,000 hatchlings) were stocked in season 1 and 620 spawns (168,912 hatchlings) in season 2 for this study (Table 1). Hatchlings were released with the brood female to more accurately stimulate natural recruitment. The resulting annual average harvest yields for this study were low, even for typical crawfish production scenarios. Overall, annual yields averaged 194 pounds/A by weight and 2,216 crawfish/A by number of individuals captured in season 1, and 360 lb/A by weight and 4,012 crawfish/A in season 2. Ponds stocked at the highest rate had the highest yield, and the lowest yielding ponds were generally those not intentionally stocked. It is unclear how non-stocked ponds became populated. Perhaps some minimal natural reproduction occurred (even though attempts were made to eliminate that source) and/or some movement of crawfish occurred after stocking. While rare to see small juveniles traversing across levees between ponds, larger crawfish will

Figure 3. A drop sampler, set and ready to trip with a slight tug on the rope from the levee. Crawfish are retrieved by pumping out the water from the caisson while the cylinder walls are in contact with the mud bottom, exposing crawfish trapped within.

sometimes migrate at night, and it is possible that some individuals may have moved between ponds via water inflow structures.

The overall capture rate in this study for ponds where crawfish were introduced were from 13 to 26% of the total number of crawfish stocked; however, when non-stocked fields were included, the capture rate increased to 17 - 28%. This is lower than anticipated, but it is unknown if this is typical of commercial ponds. Recapture rates were generally greater for the low stocking density and were greater

Figure 4. Average catch with sampling gear by sampling period (Dec, early Jan, late Jan, early Feb, late Feb, and early March).

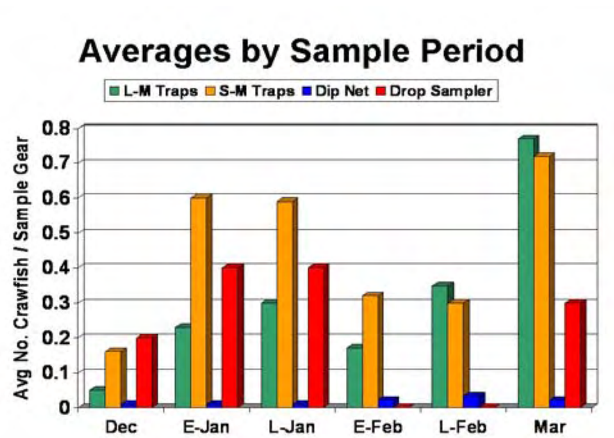


Table 1. Average number of crawfish stocked per 1-acre pond for each treatment (two replicated ponds per treatment). Multiple stockings occurred every 2 weeks from 16 October through 28 November. Single stockings occurred on 28 November. Harvesting commenced on 21 March.

Treatment[1]	No. Hatchlings	No. Adults	Total Crawfish	Density Stocked (No./m^2)	Times Stocked
0-Stocked	0	0	0	0	-
Late – Low	9,310	26	9,336	2.31	1
Low – 4	9,307	34	9,341	2.31	4
Low – 1	9,382	39	9,421	2.33	1
High – 4	28,307	110	28,417	7.02	4
High – 1	28,150	101	28,251	6.98	1
Total Stocked	168,912	620	169,532		

[1] Stocking treatments consisted of either a High (~ 7), Low (~ 2), or 0 stocking rate (crawfish/m^2), stocked over 1 or 4 occasions or on 1 occasion later in the season.

overall in season (Table 2). Assuming the residual of remaining crawfish after cessation of all harvests was similar for all ponds, these low retrieval rates indicate much higher mortality rates than survival rates for all stocking scenarios. The reason(s) for this is unclear but could possibly be associated with either fish and/or insect predators. Some small sunfish and dragonfly naiads were observed during sampling and subsequent harvests but not in uncommon quantities. Recapture rate was lower in season 1 and the numbers of fish and insect predators where higher that year (visual observations).

Results of the population sampling generally reflect higher catches with all sampling gear in season 2 when compared with season 1. This seems to be associated with higher survival since stocking rates were comparable. The highest catch per sampling period for all sampling gear occurred in February (in season 2), and depending on sampling gear, from January to March in season 1. As observed in season 1, small-mesh traps dominated the catch per unit effort early in season 2, with large-mesh traps having a slightly higher catch during late January and February. These findings reflect the relative abundance of individuals by size in the population. As crawfish grew, more were retained by the large-mesh traps. Sampling efficacy was superior for pond margins as opposed to the pond interior in both years. The correlation coefficients for all comparisons of sampling results (with respect to sampling of the pond

Results at a glance...

- *Sampling with test traps, dip-net sweeps, and a passive experimental sampler generally were good indicators of relative crawfish recruitment density and potential yield. The most accurate pond inventory methodologies were those that sampled around the pond margin rather than in the pond interior and occurred several months after the simulated recruitment period.*

Table 2. Average percent recovery of crawfish per treatment (two replicated ponds per treatment) and means per treatment factor.

Treatment	No. Crawfish Stocked	No. Captured	% Recaptured	Treatment Avg. for 1 Time[1]	Treatment Avg. for 4 Times	Treatment Avg. for Low[1]	Treatment Avg. for High
0-Stocked	0	1883	-	31.2%	25.4%	34.0%	22.6%
Late-Low	9,336	3011	32.25				
Low - 4	9,341	3078	32.95				
Low - 1	9,421	3301	35.04				
High - 4	28,417	5059	17.80				
High - 1	28,251	7739	27.39				
Overall	169,532	44,376	26.2[2]%				

[1] Excludes the Late-Low treatment.
[2] When harvests from 0-stocked ponds are included, the average percent recovery based on total stocked individuals was 28.4%.

margin) with yields were higher for season 2 (Table 3). In addition, the sampling methods were all very well correlated with stocking density, and stocking density showed good correlations to yield, especially during the second season. Based on the resulting correlations for this study, the best predictor of yield (both in weight and numbers) was the drop sampler in year 1 and large mesh traps in year 2.

Table 3. Average yield and sampler catches for edge of pond sampling with baited large- and small-mesh traps, dip nets, and drop samplers. Correlation coefficients are based on these averages by pond.

Treatment	Total Stocked	Yield (lb/A)	Yield (No.)	Large Trap Catch (No./trap)	Small Trap Catch (No./trap)	Dip Net Sweep (No./dip)	Drop Sampler Catch (No./set)
High - 1	28250	831.0	10995	4.33	4.13	0.55	
High - 1	28253	414.6	4483	3.04	4.58	0.33	0.42
High - 4	28442	523.5	5598	3.29	3.13	0.20	
High - 4	28391	411.3	4519	2.88	2.21	0.35	1.08
Low - 1	9426	348.7	3592	1.46	1.96	0.37	0.42
Low - 1	9415	283.7	3009	0.96	1.38	0.22	
Low - 4	9346	321.8	3234	1.58	1.79	0.12	
Low - 4	9336	266.0	2922	1.96	0.96	0.13	0.17
Late-Low	9333	242.1	2882	0.33	0.54	0.00	0.08
Late-Low	9339	299.4	3140	0.92	0.92	0.08	
0 Stocked	0	256.1	2424	0.75	1.38	0.07	0.17
0 Stocked	0	125.4	1341	0.50	0.42	0.02	

Correlation	Linear Correlation Coefficient (r)
Yield (lb) to total crawfish stocked	0.78817
Yield (#) to total crawfish stocked	0.73875
Large-mesh trap catch to total crawfish stocked	0.90405
Large-mesh trap catch to yield (lb)	0.89724
Large-mesh trap catch to yield (#)	0.86083
Small-mesh trap catch to total stocked	0.83878
Small-mesh trap catch to yield (lb)	0.81069
Small-mesh trap catch to yield (#)	0.75720
Dip net sweep count to total crawfish stocked	0.72302
Dip net sweep count to yield (lb)	0.82777
Dip net sweep count to yield (#)	0.80868
Drop sampler catch to total crawfish stocked	0.74367
Drop sampler catch to yield (lb)	0.80832
Drop sampler catch to yield (#)	0.79995

In conclusion, while yield was generally positively correlated to stocking density, the percentage of crawfish retrieved by trap harvesting was relatively low regardless of stocking density or number of stocking events. Without an effective method to accurately assess recruitment in commercial ponds, it is unknown how accurately these recovery numbers represent the percent recovery of crawfish in commercial operations. However, based on the high positive correlations of the sampling gears and protocols with crawfish yields these systematic sampling approaches may be suitable for assessing relative population densities of commercial crawfish ponds and, perhaps with further research, could become a useful tool to predict yield.

Objective 3. *Modify the Aquascanner Catfish SONAR system to size individual catfish collected from commercial catfish ponds*

National Center for Physical Acoustics at the University of Mississippi. Work has progressed on modifying the Aquascanner Catfish SONAR to provide information on fish size distribution in populations from commercial catfish ponds. If such information is desired in research or commercial settings, the only method currently available is to individually weigh or measure the length of fish in a subsample of the population. The method being investigated involves collecting a population subsample in a holding device (a tank, netpen, or other device) and then allowing fish to rapidly pass, one at a time, through the pipe. As fish pass through the pipe, they are pinged by acoustic pulses and the return echo amplitude is recorded and then stored on the unit or transmitted wirelessly to the host laptop. This data is then used to catalogue and size the fish.

A prototype measurement system was assembled and tested in the summer of 2005 and again in the fall of 2006. Figures 5 and 6 (reported in last years report but shown here for ease of reference) shows field data along with processed data identifying the target and ultimately its target strength or reflectivity. Fish were collected and pinged acoustically as they passed through a 6-inch PVC pipe. The large echoes from the back wall of the pipe as well as well as from fish passing by have been identified. The background noise is presumably due to entrained sediment in the

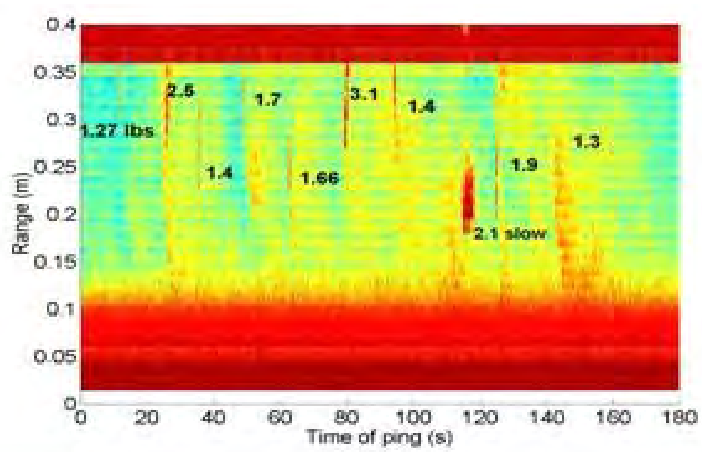


Figure 5. Fish scan data set using 460 kHz transducer.

test tank. It is noteworthy that the last fish, weighing 1.3 pounds, was not identified by the automated routine (Figure 6). Subsequent measurements have shown that the small fish (typically 0.25 pounds or less) are often missed although echo data from a 0.1 pound fish has been recorded.

In the second year of the project, two trips were made to test the system in commercial catfish ponds near Wilmot, Arkansas. These trips were used to determine the appropriate driving voltage for a pond environment and to calibrate the system. Previously we planned to determine fish weight (W) from acoustic data by using algorithms that convert acoustic target strength to fish length and then using available literature data to convert fish length to fish weight. The target strength (TS) is the amount of acoustic signal lost when reflecting off of a target and as such it represents the "reflectivity" of that target. Variation in fish weight to length relationships, together with variances in the target strength of individual fish, lead to some very large over-predictions of fish weight. To simplify the analysis, measured fish weights and measured acoustic target strengths of a fish sample were used to develop a predictive model (Figure 7). The predictive model

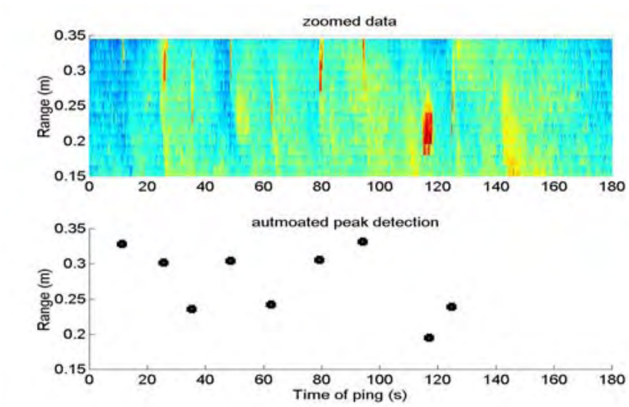
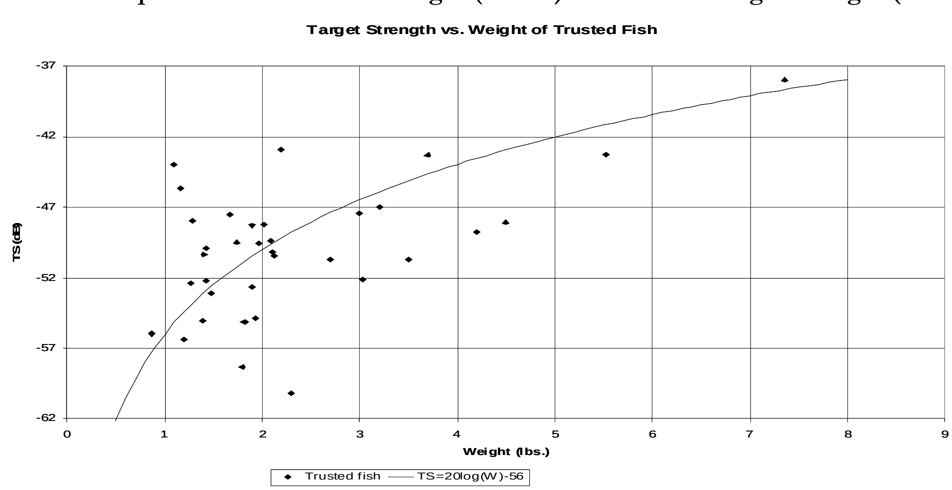


Figure 6. Fish scan data set with automated peak detector software.

Figure 7. Relationship between known fish weight (X-axis) and acoustic target strength (Y-axis)



was TS = 20(logW) - 56. In a test of this relationship using 104 fish of known weight, the predicted mean fish weight was 2.47 pounds (SD = 1.65 pounds) while the measured mean weight was 2.34 pounds (SD = 1.18 pounds).

It should be noted that the Wilmot samples did not generate adequate data on large (> 5 pounds) fish. Also, calibration runs for model development were hampered if the system missed a fish. That is, if ten fish were run through a pipe and only nine were identified, we would be unable to definitively ascribe the known measured weight to the appropriate fish's target strength to develop a proper empirical model. To address this deficiency, a portable air canister was attached to the prototype unit to provide a jet of air after every five fish were passed to provide a known calibration point in the data sample. If a fish was missed by the acoustic system only that small portion of the data would therefore be corrupted and the rest of the dataset could be used for model development. A sample of the raw data and the resulting processed data identifying the peak amplitude for each fish is shown in Figures 8 and 9. Additional modifications included placing the

Results at a glance...

- *An acoustic backscatter system has been built to measure the target strength of individual fish from a harvested population. A relationship between fish weight and acoustical target strength was developed into a predictive model that can be used to predict the population weight distribution of the fish harvested.*

Figure 8. Fish echo data with injected air bubbles to mark passage of groups of five fish.

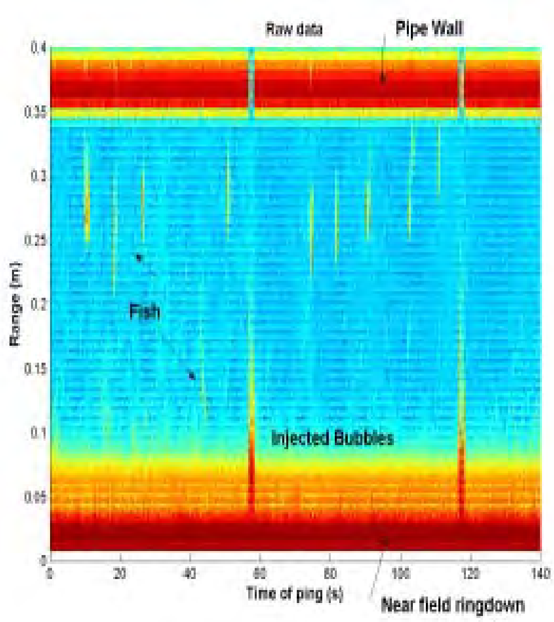
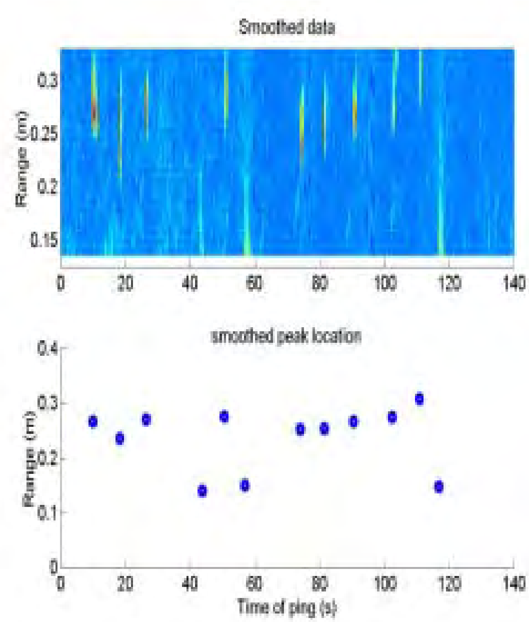


Figure 9. Fish echo data with injected air bubbles and automated peak detection software.



electronics and battery on the raft to improve portability by eliminating all physical connections to shore. The data is stored on board and transmitted vie wireless Ethernet as needed for analysis. A picture of the latest prototype unit is shown in Figure 10.

Two ponds at the University of Arkansas at Pine Bluff were used in 2009 to further validate and refine the empirical formula and calibrate the system. The first pond contained two net pens, one with small fish and one with food-sized fish. An extra net pen was used to collect the measured fish as they passed through the acoustic system so they could be returned to their original pens. The second pond, shown in Figure 11, contained brood fish. Fish confined in a

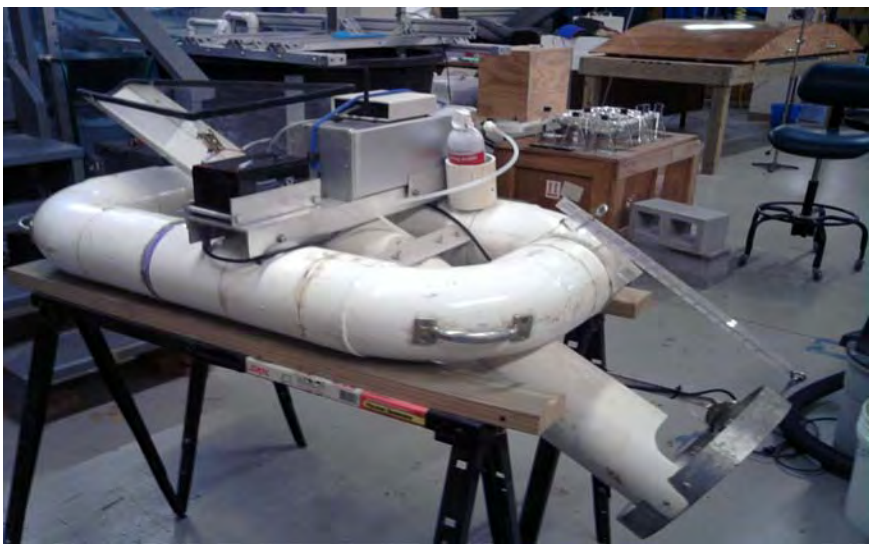
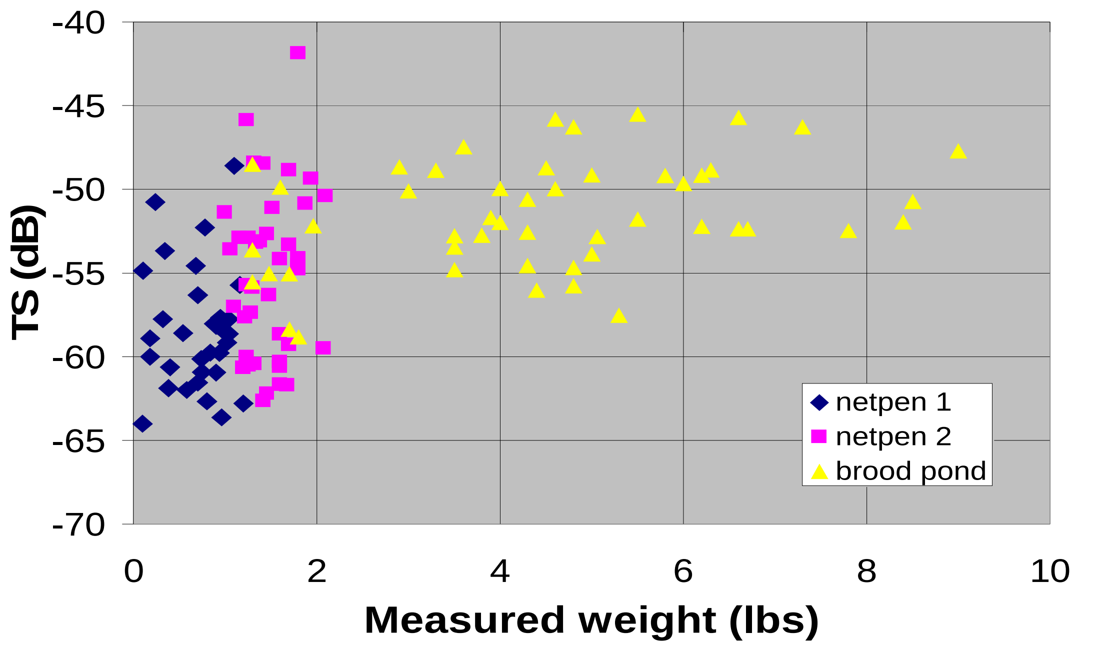


Figure 10. The catfish sizing system with electronics and battery mounted on board and bubbler system in place to provide calibrated signal in data.

Figure 11. Modified Aquascanner Catfish SONAR system being used to measure individual fish.

net and released after they were measured. The preliminary dataset is shown in Figure 12. The overall relationship was similar to that in the Wilmot data, with small fish averaging an approximately -57 dB target strength, food-sized fish averaging a larger (approximately -53 dB) target strength and brood-sized fish averaging a still higher -50dB target strength. The Pine Bluff data appears to have a systemically lower target strength for a given fish weight than the Wilmot data, but it is unclear if this is due to an equipment change, a measurement change or simply the results of having a larger dataset. Data from these ponds is still being processed and final results will be included in the project final report.

Figure 12. Relationship between target strength (TS) and measured fish weight from a pond at Pine Bluff, Arkansas.



Objective 4. *Develop and evaluate several down-looking and low frequency side-scan sonar technologies to determine numbers of channel catfish in ponds.*

Mississippi State University. First year research focused on obtaining and testing the inventory potential of a 997c Humminbird side-imaging sonar unit. The 997c transducer has both a down-looking 83 kHz/200 kHz lobe and a side-scanning 455 kHz/800 kHz lobe. The side imaging sonar must be moving to operate properly; therefore, it was mounted on a boat equipped with an electric-start outboard motor, console steering, and a trolling motor. These features make it possible for one person to control the boat path and the sonar functions (monitoring images and making recordings when appropriate). Initial sonar evaluation trials were conducted in a 64.7-ha lake stocked with bass, bream, crappie, and a 2.4-ha catfish pond stocked with food-sized catfish. The lake has extensive shallow (0.6-1.8 meters) and deep (up to 6 meters) areas including a flooded creek. The catfish pond was build with a smooth flat bottom ranging in depth from 0.6 to 1.8 meters. The 997c side-scan lobe produced excellent images of the pond bottom and various structural features in both shallow and deep water; however, the unit must be operated 455 kHz in shallow water because the higher frequency saturates the water column making imaging impossible. The down-looking lobe has an advanced fish-imaging feature that works well in deeper water but not in water as shallow as most catfish ponds. We were able to record and save images as "Screen Snap Shots" on SD memory cards for play back on the 997c or reviewed later after transfer to a computer. This preliminary work indicates that the side-scan lobes can be used to image fish.

An agreement between Mississippi State University and the Weatherford Company (specializes in pipeline leak detection services) in Houston, Texas for per day rental of a DIDSON system was completed in March 2009. The rental unit includes a DIDSON 300M (300-meter imaging range), a 50-foot sonar cable (other lengths are available), a 24-volt DC power supply with power cord, a Topside Box, a 10-foot Ethernet cable to connect a laptop computer to the Ethernet port on the Topside box, a hardcopy of the DIDSON setup manual, and a CD containing a proprietary file that must be loaded onto the laptop to operate the sonar.

The DIDSON 300M can be operated at either a high- (1.8 MHz) or low- (1.1 MHz) frequency. The high operating frequency produces 96 beams with a two-band width of 0.3 degrees horizontal by 14 degrees vertical, and a range of 1 to 15 meters. The low operating frequency produces 48 beams with a two-band width of 0.6 degrees horizontal by 14 degrees vertical, and a range of 1 to 35 meters. Both modes have a 29 degree field of view and can set to record at a maximum frame rate of 4 to 20 frames per second depending on the window length. The sonar lens can focus from 1 meter to the maximum range as determined by the operating frequency and environment.

Objectives were 1) to evaluate and then select a mobile power sources for use in a boat 2) to design and build a detachable DIDSON deployment system that can be easily fitted to a commercial seining boat, 3) to develop an effective fish stabilization system, 4) to continue improving our skills at acquiring the best possible images, and 5) to determine the counting and sizing capability of the DIDSON software relative to catfish size and numbers in production ponds.

The three possible power sources are 1) a generator (diesel or gas), 2) a 24-volt battery system, and 3) a 12-volt battery connected to a sufficiently powerful power inverter. In an aluminum boat, even a small generator would produce high levels of noise that would likely move fish away from the sampling area thus making the acquired data unreliable. The 24-volt DC current required to operate the DIDSON could be supplied by connecting a large, high-amp, 24-volt battery to the Topside Box power supply port; an additional 110-volt power source would be needed to operate the laptop. The third option was chosen because a high-amp gel cell 12-volt battery connected to a 400-watt (or higher) 12-volt DC to AC power inverter produces sufficient 110-volt AC current to quietly power both the DIDSON and a laptop for several hours.

The DIDSON unit was deployed using a custom-made, adjustable system that allows quick deployment to the desired depth and rapid re-deployment for multiple sampling. Details of the deployment system and data-processing options for the DIDSON unit can be obtained from Dr. C. D. Minchew at Mississippi State University.

In initial samplings, high and low frequency sonar data were collected at 8 to12 stations in five, 9-acre ponds (low frequency data; LF), four, 7-acre ponds (high frequency data: HF), and six, 4-acre ponds (LF). The quality of the catfish images observed on the laptop in live view and in playback was adequate, but excessive boat movement made it unlikely that data could be used to generate accurate information on the size and number of catfish in ponds. We stabilized the boat using metal stakes secured with brackets, which stopped most boat motion in shallow water. A second set of HF samples were then obtained from five, 4-acre ponds.

The strength of the DIDSON sonar for studying catfish in shallow production ponds is its ability to record recognizable images of fish in turbid ponds and process that data to obtain estimates of fish size. Useable images have been taken with both the low- and high-frequency beams. Under ideal conditions, ranges of the high- and low-frequency beams are 1-15 m and 1-35 m, respectively. However, in the present study, the useful range of the two sonar beams was limited to about 8 m (high frequency) and 16 m (low frequency). While the low frequency beam has a longer range, it is limited in its ability to image small fish. Therefore, the high-frequency setting was used to image obtain the following images. Figure 13 shows a large and small catfish

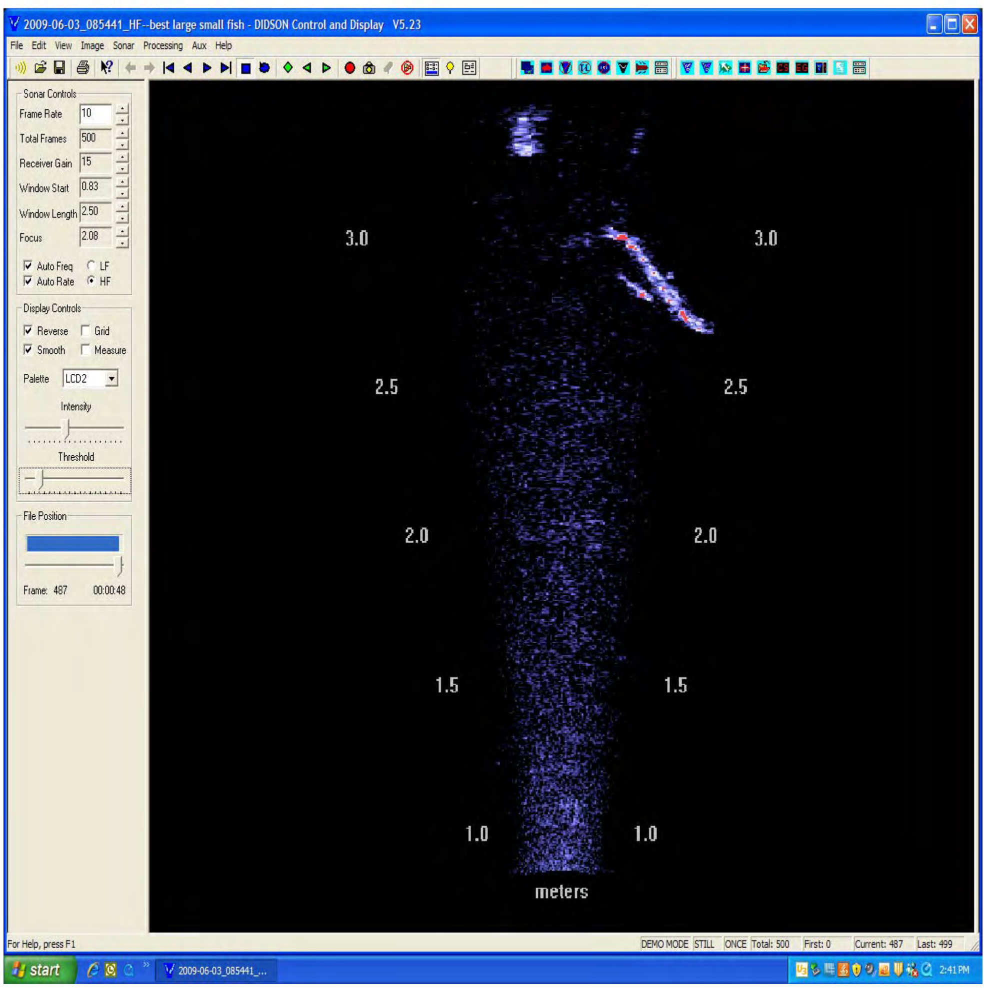
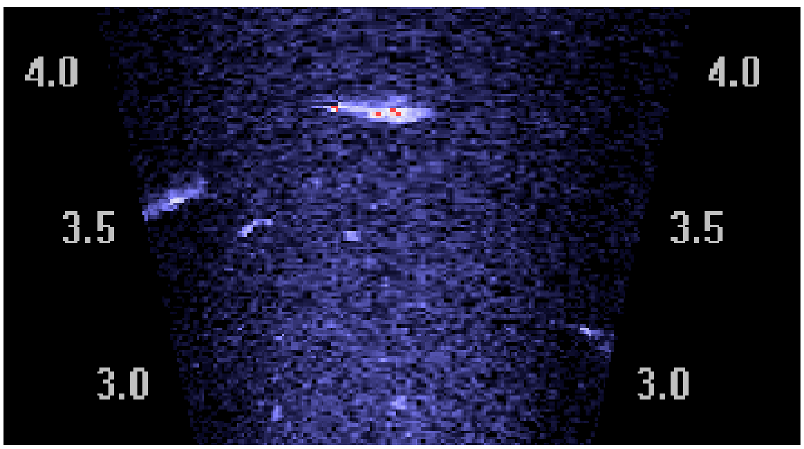


Figure 13. A sonar image of a large (58 cm) and small (16 cm) catfish swimming near each other. The sonar image was taken at a sampling station at Delta Research and Extension Center on August 3, 2009. The pond had recently been stocked with two size classes of catfish as a part of a growth study.

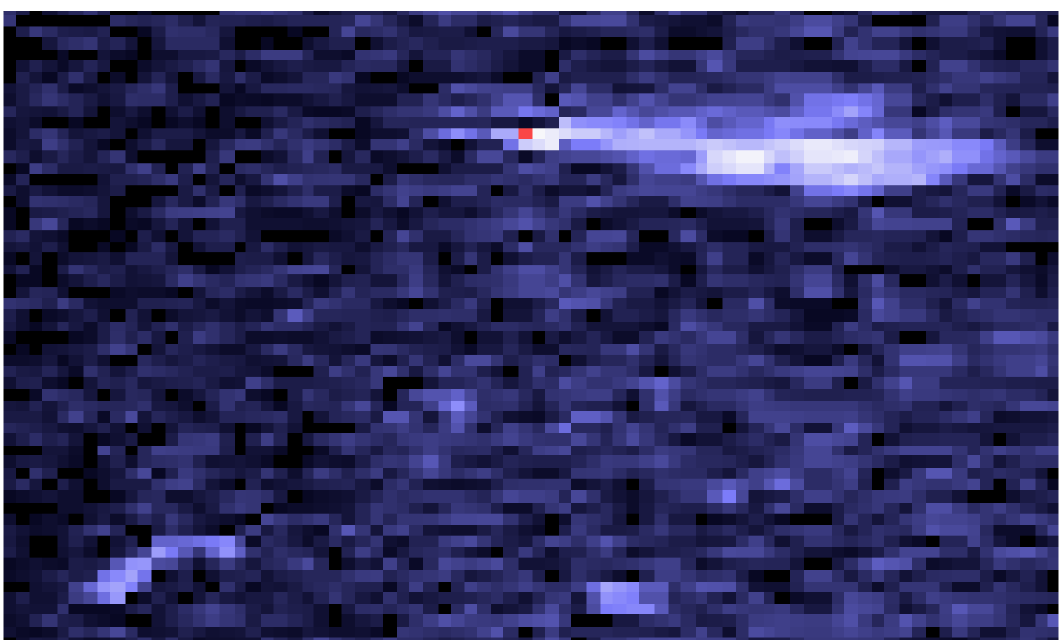
swimming together. Fish were sized using the DIDSON "measure tool." The fingerling was (6.3 inches) and the larger fish was 58 cm (22.8 inches). Another frame illustrating the ability of the DIDSON to image large and small catfish is shown in Figure 14. Figure 14A shows the raw image and Figure 14B shows the image of the large and small fish focused at 1 meter. When sized as raw data the large catfish measured 38 cm (15.0 in) and the small catfish measured 12 cm (4.7 in). When the image was

Figure 14. DIDSON sonor image captures. (A) Raw data file showing a large catfish to the right of the 3.5 m mark (left side), a much small catfish below and to the right of that fish, and a large catfish in the middle of the image. (B) A focused image (zoomed to 1 m) of the small fish (bottom left) and the centered large fish.

A



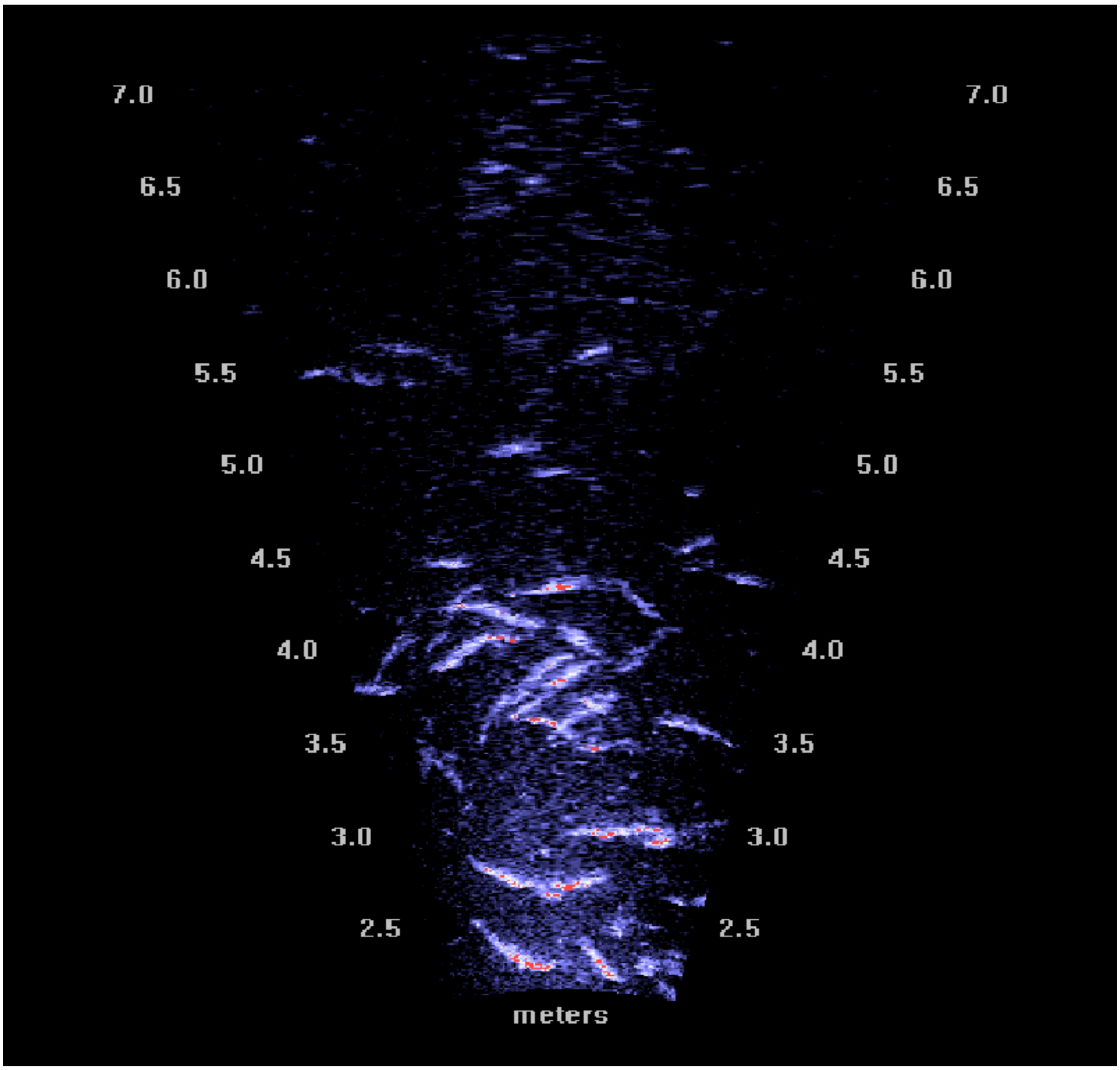
B



focused to 1 m using the focus tool, the large fish measured 39 cm (15.4 in) and the small fish measured 13 cm (5.1 in). In many cases, it was much quicker to measure the fish (especially small ones) using the focus tool rather than making measurements from the raw data file.

Although not a part of this study, it is clear that the DIDSON has the potential to be useful in studying catfish behavior. It could be used to observe the behavior of pond cultured catfish in response to seining, grading, low oxygen, and feeding. For example, Figure 15 shows an image collected while

Figure 15. Raw data image of feeding fish.



catfish were being fed fed using a tractor-pulled feeder. Additional images were collected during a severe dissolved oxygen depletion. Both events (feeding and response to low oxygen) are more impressive when examined while running the video of each event rather than as still pictures.

Determining the inventory capability of the DIDSON is not complete. The automated sizing and counting features seriously underestimate the number of fish in sonar samples taken at the sampling stations in each pond. The software uses the background subtraction and "detect motion" tools to highlight the fish it counts in blue or green and questionable images in red. Generally, the red images represent additional uncounted fish. Part of the problem is how the software tracks the imaged fish. Since it was developed for sampling fish in flowing water, fish that the software recognizes as swimming up stream through the window are counted; if they then swim back through the window they are subtracted. Boat and sonar motion also causes errors in the automated sizing and counting software. If only large fish (above about 20 cm) are being counted, activating the background subtraction and detect motion features will speed up the process of taking manual counts.

Fish in each dataset can be manually counted by increasing or decreasing the frame rate during playback which helps insure that a fish moving across the window (often takes several frames) is counted only once. The process of manually counting the usable data collected thus far is ongoing.

Results at a glance...

- *The DIDSON sonar with its sophisticated software can detect, identify, and measure catfish cultured in shallow, turbid waters. Catfish as small as 10 cm and as large as 65 cm have been detected, imaged, and measured using sonar data files collected at multiple sampling sites in culture ponds stocked with mixed sizes of fish. Such data could be used to develop population size distributions for commercial ponds.*

Objective 5. *Develop and evaluate a catfish trawl and portable computing technologies to estimate size distribution and biomass in catfish production ponds.*

University of Arkansas at Pine Bluff. A sampling apparatus was constructed with two major components: 1) a commercially available "otter trawl" with a 9-m (30-foot) opening (Figure 16), and 2) a standard seine reel fitted with an increased drum diameter and a PTO-driven, self-contained hydraulic system. This reel system can hold over 1,500 feet of high strength, low-stretch rope, and is capable of pulling the trawl through the pond at a rate of 5' per second (Figure 17).

In a preliminary study, the catfish trawl was pulled once across three commercial catfish ponds. All captured fish were individually weighed to assess the size distribution of the fish in the trawl. The day following the trawl pulls, ponds were seined twice with a fingerling seine to capture all the fish in the pond. Seined fish were transferred to a sock and a random sample of fish was captured from the sock with a hoop-net. Sampled fish were individually weighed to assess the size distribution of the fish captured with the seine.

In our first trial, the average weight and the size distribution of the fish obtained from each sampling gear were significantly different for the three ponds tested. The proportion of fish larger than 0.32-kg (0.75 pounds) was significantly larger in the sample

Figure 16. The "otter trawl" is shown here laid out and ready to be pulled across a pond.

Figure 17. Tractor (43hp) used to pull the trawl using a power take-off driven hydraulic pump.

collected from the trawl. However, the range of fish sizes (minimum and maximum) caught by each method appeared similar, suggesting that the trawl has the capacity of capturing fish of all sizes (Table 4). Besides, the quantity of fish captured with one pull of the trawl did not appear to be related to the quantity of fish in the pond (Table 5).

In a second trial, the trawl was pulled across a commercial catfish pond four successive times over a two day period to test the variability in trawl sampling. The total quantity of fish captured in each trawl pull varied from 280 to 375 kg (656 to 859 pounds; Table 6). Results indicated that the average fish sizes and the fish size distribution were

Table 4. Comparison of the average size (± std. dev.) of fish captured with a seine and with a trawl from three different commercial catfish ponds.

		Fish Weight		
Treatment	Fish Sampled	Average (lb)	Min. (lb)	Max. (lb)
Pond A1				
Seine	428	0.80±0.59	0.10	3.64
Trawl	525	0.92±0.61	0.18	4.39
Pond A2				
Seine	474	0.63±0.35	0.04	3.77
Trawl	86	0.97±0.66	0.09	3.99
Pond B1				
Seine	621	0.56±0.33	0.02	2.68
Trawl	142	0.70±0.35	0.16	1.98

Table 5. Comparison between the quantity of fish captured with two seine hauls and a trawl pull across three commercial catfish ponds.

	Seine		Trawl	
Pond	Total (lb)	Sample (lb)	Total (lb)	Sample (lb)
A1	37,090	341	646	484
A2	24,020	297	84	84
B1	36,230	348	100	100

Table 6. Characteristics of four successive trawl samples collected from a single commercial catfish pond.

	Total		Fish size		
Sample	Weight (lb)	Number (fish)	Av. ± SD (lb)	Max. (lb)	Min. (lb)
1	767	1,026	0.75±0.54	2.82	0.02
2	741	1,150	0.64±0.52	2.88	0.03
3	656	752	0.87±0.59	4.35	0.02
4	859	922	0.93±0.59	6.58	0.03

significantly different among trawl pulls due to the presence of very large fish in two of the samples.

Additional trials were conducted to determine if feeding in conjunction with trawling influenced the precision and accuracy of the trawl for estimating commercial catfish pond inventories. In the fall of 2008, six, 10-acre catfish ponds were selected randomly from a farm in south Arkansas for the trawling experiment. In each pond, the trawl was pulled once without feeding, and once with feeding. All fish caught in each trawl pull were individually weighed. Ponds were then seined three times with a small mesh seine to estimate the actual pond inventory using the Depletion Estimation technique. Samples were taken from each of these seine pulls and individual weights were taken to generate "actual" size distribution data. Total pond biomass estimates were generated from the trawling data by utilizing the "swept area method" commonly employed in natural fisheries. Because no values of fishing efficiency (q) were known for this trawl, or for this type of fishing effort, a fishing efficiency of 1 was assumed for this preliminary analysis.

Results at a glance...

- *The catfish sampling trawl captures large stockers and foodsize fish more effectively than it does fingerlings. Nevertheless, the trawl may still remain a viable sampling technique to assess the size distribution of catfish populations after these biases are quantified.*

Trawling with feed did not result in a significant increase in total weight of fish caught as compared to trawling without feed. Mean individual wts of fish caught were similar in both treatments and were generally not significantly different from the actual population. However, in two of the six ponds, the distribution of fish caught from the trawling without feed treatment was shown to be different from the actual. Total biomass inventory estimates based on these trawl samples significantly underestimated the total inventory. This suggests that the fishing efficiency value (q) of the trawl is less than 1. These data are currently be analyzed.

Further trials were conducted in six, 4-acre (1.6 ha) experimental research ponds at the Thad Cochran National Warmwater Aquaculture Center at Stoneville, MS. In these trials, ponds were stocked with multiple batches of fish in the spring 2009. Trawl sampling data was collected within several weeks of stocking and this data is being compared to the actual stocking data from those ponds.

In the first set of trials each pond was trawled once without feeding and once with feeding. Size distribution data generated from the trawl pulls was compared to the original stocking records using the Kolmogorov-Smirnov test. In these trials, trawling with feeding caught significantly more fish than trawling without feed, but the size distributions were not different from each other and were not different from the original stocking data. However, the mean individual length of catfish stocked (24 ±0.03 cm) was significantly lower than that of the trawl treatments (30 ± 0.52 cm without feed, 30±0.57 cm with feed). This might be explained in part by the fact that the mesh size of the trawl allowed some of the smallest fingerlings to grade out. Total biomass estimates generated with the swept area method described above and the mean inventory estimation errors are currently under analysis.

Another set of trials in these same ponds was designed to compared the inventory estimates generated from one, two, or three consecutive trawl pulls (without feeding) to that of the known population. Because we know the details of the actual fish population stocked, we can use our catch per unit effort data to determine if three trawl pulls improves our biomass estimation. The trawling data generated by this study allow us to calculate a fishing efficiency value (q) for this trawl under these defined circumstances. We are currently refining our analysis to help us to better define this value. With this critical piece of information, biomass estimation with the swept area method should be much improved. We are also scheduling more trials on commercial catfish production ponds to determine if three trawl pulls without feeding, and a better estimate of the fishing efficiency of the trawl would result in more accurate biomass estimation.

Estimating the size distribution of a fish population entails weighing a large number of fish individually on the pond bank. The standard method of recording the individual weight data requires one individual putting the fish on a bench scale and another individual writing the weights on a sheet of paper. Later, the data need to be typed into a computer spreadsheet for analysis. Unfortunately, it may take several hours or even days to finally get the data into a computer and get a report printed for the farmer. The delay prevents farmers from making timely, well-informed management decisions.

One solution to this problem is to have the bench scale connected by a serial cable directly to a laptop computer at the pond bank. The weight data can be transferred automatically from the scale to the computer and processed in a timely fashion. Unfortunately, laptop computers are not suited for use in harsh, dusty, and wet environments.

Handheld computers (PDA, Palm Pilot, or Pocket PC) appear to be the most efficient tools to use for weight data collection and processing in the field. After numerous field trials, a collection of reliable hardware and user friendly software available commercially have been identified for farmers or researchers desiring collecting and processing fish weight data from the pond bank (Figure 18). The measured weights on a bench scale can be transferred

Figure 18. Equipment used to efficiently assess the size distribution of large fish samples.

and recorded directly to an Excel spreadsheet on a PDA. The Excel spreadsheet can display the updated overall average fish weight and total fish count automatically after each new data entry. Besides, the data can be safe and protected from PDA malfunctions or breakdown if the Excel file is located on an SD card inserted in the PDA. Reports can also be printed in the field with a wireless portable printer. Later, the Excel file can be easily transferred to a desktop computer for further processing. Details on equipment and procedures can be obtained from David Heikes at the University of Arkansas at Pine Bluff. The use of trade, firm, or corporation names is for information and convenience only. Such use does not constitute an official endorsement or approval by the author, the University of Arkansas at Pine Bluff, or the University of Arkansas Division of Agriculture Cooperative Extension Service, of any product or service to the exclusion of others that may be suitable.

IMPACTS

Results from this project could have a significant impact with producers, especially in the estimation of ornamental fish egg-layer fry. These impacts could not only reduce time spent on spawning tank set-up and subsequent cleaning but could also increase production if the actual fry numbers could be reared through to the juvenile stage.

Another benefit of this project relates to the U.S. Department of Agriculture, Commodity Credit Corporation, Non-insured Crop Disaster Assistance Program (NAP), which now requires ornamental fish producers to maintain an accurate, ongoing inventory as per the following quote: "The State Committee determined to require all producers with NAP value loss crops, to maintain a monthly inventory. These maintained monthly inventory numbers can be used for spot checks, if needed, and in the event of a disaster occurrence. Records are to be kept up to date and readily available upon request." With data obtained in future studies of a second egg-layers species, blue gouramis (*Trichogaster trichopterus*) as well as one live bearing swordtail (*Xiphophorus hellerii*), the eventual completion of a computer-based spreadsheet will not only help the producers with their efficiency but will also provide data for NAP inventory requirements.

While much of these findings on crawfish inventory methods must also be considered preliminary, their usefulness lies in the providing of a foundation which can be used to develop a better understanding of the relationship between initial recruitment numbers, surviving population density and structure, and resulting yields. This should lead to better management recommendations and options for maximizing profits

The trawling data generated by this study will allow us to calculate a fishing efficiency value (q) for this trawl under these defined circumstances. With this critical piece of information, biomass estimation with the swept area method should be much improved.

One major catfish producer in Mississippi has adopted the sampling trawl techniques developed by this project. By utilizing size distribution data generated from fish captured by trawling, the production manager has been able to more accurately pinpoint production ponds that are currently ready for harvest and to schedule harvest dates for ponds that are not currently ready.

The new data collection system resulting from this work has already been used by University of Arkansas at Pine Bluff Extension specialists who routinely assess size distribution of large fish samples on commercial catfish farms. The system minimizes labor necessary for data collection and makes processed data immediately available for making management decisions.

PUBLICATIONS, MANUSCRIPTS OR PAPERS PRESENTED

McClain, W.R., R.P. Romaire, and J.J. Sonnier. 2007. Assessment of sampling and harvest yields when crawfish ponds are populated only by stocking of hatchlings. LSU Agricultural Center, Rice Research Station Annual Research Report 99:233-246.

McClain, W.R., R.P. Romaire, and J.J. Sonnier. 2008. Assessment of sampling and harvest yields when crawfish ponds are populated only by stocking hatchlings.LSU Agricultural Center, Rice Research Station Annual Research Report 100:188-201.

Heffington, J.D., Chambers, J.P., Heikes, D., Pomerleau, S., Stone, E. 2006. Using acoustic backscatter to determine the size distribution of channel catfish in a commercial pond. The 152nd Meeting of the Acoustical Society of America. Honolulu, Hawaii.

◆ ◆ ◆

ECONOMIC FORECASTING AND POLICY ANALYSIS MODELS FOR CATFISH AND TROUT

Reporting Period
August 1, 2007 - August 31, 2009

Funding Level	Year 1	$75,000
	Year 2	75,000
	Total	$150,000

Participants	University of Arkansas at Pine Bluff	Carole Engle
	Louisiana State University	P. Lynn Kennedy, Jeffrey Gillespie
	Mississippi State University	Terry Hanson, Darren Hudson, John Anderson, and Andrew Muhammad
	North Carolina State University	Jeffrey Hinshaw
	University of Florida	Charles Adams

Administrative Advisor Dr. Ivory Lyles
Vice President for Agriculture-Extension
University of Arkansas

PROJECT OBJECTIVES

United States aquaculture industries and their product markets have matured such that the dynamics of the national economy, federal and state policies, and international trade can have significant and unanticipated effects on the financial health of U.S. aquaculture businesses. Other segments of the agriculture and food sectors rely upon and benefit from econometric models that estimate demand, supply and the relationships among key economic parameters. These models are used to forecast industry trends, effects of anticipated macro-economic factors, and impacts of proposed policy initiatives. Linking general macroeconomic trends to aquaculture production and market sectors and following the effects through to the resulting impacts on farm price levels will provide guidance on policy initiatives for the catfish and trout industries.

Results at a glance...

- *Economic models have been developed of demand and supply of catfish at both the farm and wholesale levels. The variables with significant effects on catfish supply and demand were identified for both the farm and wholesale levels*

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Identify, develop, and validate economic forecasting models of catfish and trout.*

Objective 1a. *Identify, develop, and validate economic forecasting models of catfish and trout: demand and supply effects.*

Mississippi State University. Demand and supply models (Appendix A) were developed to provide an indication of changes in catfish prices and quantities at the domestic wholesale and farm levels. The model generates output related to the effects of detrimental price shocks on the price and quantity demanded of catfish and who will bear the costs.

Demand and supply models were developed based upon quantities and prices of production inputs (such as feed ingredients, fuel, and electricity), prices and quantities of raw products used in the manufacture of production inputs, and competitive markets bidding for these same raw materials or production inputs. Models at the processing sector include different sets of inputs than in the production sector, such as different labor wage rates, technologies, price expectations, taxes and subsidies. An import tariff "shock" was then applied to demonstrate how the model results would be affected.

The catfish model has been updated and significantly improved since the last SRAC Annual Report. Wholesale and farm-level demand and supply results are presented in Appendix A, Table 1. Short and long-run supply and demand elasticities were estimated for important wholesale and farm level variables (Appendix A, Table 2). These elasticities show the degree of change that will occur in one variable as a result of changes in other variables.

These equations were used to estimate the effects before and after imposing a tariff on imports in terms of welfare changes to buyers and producers at the domestic wholesale level (Appendix A, Table 3). Without any tariff, the wholesale price and quantity were $2.30 and 23.76 million pounds. The equilibrium farm price was $0.72. Consumer and producer welfare at the wholesale level are $34.29 million and $25.63 million, respectively. Processor revenue is $54.47 million. Assuming that farm sales are twice the quantity at the wholesale level, farm revenue is $33.97 million. With the tariff on imports (35% price increase on imported catfish), the wholesale quantity would increase to 23.98 million pounds, which is a difference of about 314 thousands pounds or 1.33%, and the wholesale and farm price would increase by $0.07 and $0.03, respectively. Both consumer and producer surplus would increase by about 2.7% and 4.7%, respectively. Lastly, with the tariff, processor revenue increases by $2.45 million (4.5%) and farm revenue increases by $2.00 million (5.9%).

Trout demand and supply models will not be as robust as for the catfish models because there is less data available overall (only annually available from NASS) and fewer NASS trout variable categories than for catfish. Development of these models from available data will be used to provide an indication of changes in trout prices and quantities at the domestic wholesale and farm levels. The model generates output related to the effects of detrimental price shocks on the price and quantity demanded of trout and who will bear the costs. Trout NASS data includes volume and value figures for fingerlings, stockers, and foodsize fish. Unlike the catfish model, the trout model will be estimated with annual data. Industry experts will be consulted to obtain the needed relationships associated with missing information to complete the model.

Objective 1b. *Identify, develop, and validate economic forecasting models of catfish and trout: international trade effects.*

Louisiana State University. An international trade model for the domestic catfish and trout industry was developed to estimate the effect of import supply of fish on the domestic prices of catfish and trout (full reports of work on this objective are available from Lynn Kennedy, Louisiana State University, lkennedy@agcenter.lsu.edu).

Catfish

Co-integration analysis and inverse demand models were developed to evaluate international trade effects related to catfish. This study used monthly data ranging from January 1993 to December 2004 and examined five finfish species (catfish, trout, tuna, tilapia, and salmon) and shrimp. Data of imported quantities and value of these fish were obtained from the National Marine Fisheries Service (NMFS). The unit prices of imports were obtained by dividing total value by volume of imports and were used to identify the long-term equilibrium relationship between domestic catfish and individual imported fish prices.

This work examined the interdependence between the domestic catfish price and imported fish prices in the U.S. fish market with cointegration analysis. A second analysis quantified the level of substitutability among the domestic catfish and imported fish through development of inverse demand system analyses.

For price interdependence, this study used bivariate and multivariate cointegration analyses. Cointegration tests are preceded by seasonal and non-seasonal unit root tests. The multivariate cointegration test indicates that four imported seafood among six form one common market with domestic catfish. Furthermore, the multivariate cointegrating regression shows that imported salmon, tuna, and shrimp have relatively strong price interdependence with domestic catfish, while imported catfish, trout, and tilapia have relatively weak interrelationship with domestic catfish during the sample period of time (Table 1).

To identify the degree of quantity substitutability, this study uses inverse demand systems. Contrary to our hypothesis, domestic and imported catfish are net and gross quantity complements. The scale elasticities show that domestic catfish, imported catfish, trout, tuna, tilapia, and salmon are normal goods while imported shrimp is an inferior good. For domestic catfish, only imported trout is a net substitute. However, not only imported trout but also imported tuna, salmon, and shrimp are gross substitutes for domestic catfish (Tables 2, 3, and 4).

Results at a glance...

- *Economic models of international trade effects have been developed for catfish and trout. Price of domestic catfish is more negatively influenced by imports of major seafood products such as salmon, tuna, and shrimp than by imports of catfish. This occurs because domestic and imported catfish are net and gross quantity complements. For domestic trout, the intensity of substitutable interaction of imported products is as follows, from greatest to least: frozen fillet; frozen whole trout; fresh whole trout; and rainbow trout. Depreciation of the U.S. dollar relative to exporting countries' currencies reduces the negative impact of imported trout on the domestic price.*

In order to identify the compatibility of two methodologies, this study calculates the Allais coefficients. According to the results of these two methodologies, a stronger price interrelationship leads to stronger quantity substitutability. For example, imported salmon, tuna, and shrimp show both strong price interrelationship with and quantity substitutability for domestic catfish. In contrast, imported catfish, trout, and tilapia show both relatively weak price interrelationship with and substitutability for domestic catfish (Table 5).

One finding to be noticed in this study is that the U.S. domestic catfish industry can be more negatively influenced from imports of major seafood like salmon, tuna, and shrimp than from imports of catfish. However, few studies have been reported to identify the consumer behavior in seafood consumption in the U.S. seafood market. These additional studies will help to frame seafood policy for policy makers.

Trout

Similar analysis was conducted for the U.S. trout industry. Faced with a change in trout imports, this study attempted to identify how imports affect the U.S. domestic trout industry. In doing so, this study analyzed the quantity effect and exchange rate effect on domestic trout price. During the last two decades, trout imports have changed from primarily that of frozen products to fresh or chilled products. Also, the major exporting country has changed from Argentina to Chile for frozen products and to Canada for fresh trout. According to the results of this study, we found five important facts related to trout imports during this sample period (Tables 6, 7, 8, and 9).

First, empirical results show that net effects of imported trout products are complementary rather than substitutionary for domestic trout. As a result, the low farm price of domestic trout might be due to other reasons than just increased trout imports. One possible reason is that with recent enlargement of the U.S. seafood market, U.S. seafood consumers' preference for other seafood species has increased relative to trout. This implication suggests the need for development of value-added trout products as a means of strengthening the economic growth of the U.S. domestic trout industry.

Second, in light of the relationship between domestic trout price and consumer expenditure, domestic trout price decreases with an increase in total trout supply into the domestic market. When we take imports of frozen trout fillets into consideration as a major imported product, the increase in imports of Chilean products exerts the greatest influence on U.S. domestic trout price.

Third, imported frozen trout fillets and whole products are gross-substitutes for domestic trout, while imported fresh whole trout are gross-complements to domestic trout. In particular, the import price of frozen trout is much lower than that for fresh trout. In 2008, the import prices for frozen trout fillets and whole trout were $5.29 and $4.19 per kilogram while the import prices for fresh whole trout was $6.24 per kilogram. As a result, any increase in the imports of low priced frozen trout products are a source of concern for the U.S. domestic trout industry.

Fourth, the estimated Allais coefficients show that own product has the strongest level of substitutability as compared to those for cross products. For domestic trout, the order of intensity of substitutable interaction for imported trout is as follows, from greatest to least: frozen trout fillets; frozen whole trout; fresh whole trout; rainbow trout.

Finally, depreciation of U.S. currency in terms of the major trout exporting countries' currencies has helped to reduce the potentially negative impact of increased trout imports on the U.S. domestic trout price.

Table 1. Results of the Multivariate Cointegrating Regressions

Multivariate Cointegration Regression: (Between Price Variables)

$$p_{cd} = -0.01 + 0.02\,p_{ca} + 0.04\,p_{tr} + 0.21\,p_{tu} + 0.02\,p_{ti} + 0.38\,p_{sa} + 0.11\,p_{sh}$$

(-2.18) (0.98) (1.51) (6.14) (0.77) (7.77) (1.95)

$R^2 = 0.53$

Unit Root Test for Residual ADF Test with	
Constant	Constant & Trend
-2.99	-2.94

Results of the Likelihood Ratio Test

Eigenvalue	Likelihood Ratio	Ho: *r*	F-value	Pr > F
1.1815	0.1429	0	9.24	<.0001
0.6293	0.3117	1	7.11	<.0001
0.4147	0.5078	2	5.72	<.0001
0.2044	0.7184	3	4.22	<.0001
0.1283	0.8653	4	3.21	0.0009
0.0222	0.9763	5	1.18	0.3202
0.0020	0.9980	6	0.39	0.5309

Table 2. Quantity and Scale Elasticity Coefficients Estimated by DIRDS

	Catfish(D)	Catfish(M)	Trout	Tuna	Tilapia	Salmon	Shrimp	dlnQ
Catfish (D)	-0.0324	0.0052	-0.0214	-0.0001	0.0103	0.0073	0.0310	0.0722
	(0.003)	(0.007)	(0.000)	(0.617)	(0.000)	(0.288)	(0.001)	(0.000)
Catfish (M)		-0.0018	0.0016	0.0000	-0.0009	0.0030	-0.0071	0.0001
		(0.016)	(0.088)	(0.000)	(0.242)	(0.067)	(0.000)	(0.948)
Trout			-0.0017	0.0004	-0.0001	0.0014	0.0004	-0.0006
			(0.000)	(0.3685)	(0.788)	(0.015)	(0.504)	(0.355)
Tuna				-0.0004	0.0001	0.0003	0.0000	0.0017
				(0.000)	(0.018)	(0.028)	(0.941)	(0.000)
Tilapia					-0.0105	0.0099	-0.0115	0.0054
					(0.000)	(0.000)	(0.000)	(0.096)
Salmon						-0.0433	0.0188	0.0270
						(0.000)	(0.015)	(0.003)
Shrimp							-0.0326	0.7533
							(0.049)	(0.000)

System $R^2 = 0.8805$
( ) is *p*-value

Table 3. Compensated Quantity and Scale Elasticity

	Catfish(D)	Catfish(M)	Trout	Tuna	Tilapia	Salmon	Shrimp	dlnQ
Catfish (D)	-0.148	0.024	-0.098	0.000	0.047	0.034	0.142	-0.669
Catfish (M)	1.924	-0.649	0.582	-0.001	-0.326	1.098	-2.629	-0.947
Trout	-12.623	0.924	-0.989	0.212	-0.047	0.811	0.223	-1.341
Tuna	-0.001	0.000	0.003	-0.003	0.001	0.002	0.000	-0.987
Tilapia	0.531	-0.045	-0.004	0.007	-0.540	0.509	-0.591	-0.725
Salmon	0.065	0.026	0.012	0.002	0.087	-0.382	0.166	-0.762
Shrimp	0.060	-0.014	0.001	0.000	-0.022	0.037	-0.064	0.468

Table 4. Uncompensated Quantity Elasticity

	Catfish(D)	Catfish(M)	Trout	Tuna	Tilapia	Salmon	Shrimp
Catfish (D)	-0.294	0.022	-0.099	-0.088	0.034	-0.042	-0.201
Catfish (M)	1.718	-0.651	0.581	-0.125	-0.345	0.990	-3.114
Trout	-12.916	0.921	-0.991	0.036	-0.073	0.659	-0.466
Tuna	-0.216	-0.003	0.001	-0.133	-0.018	-0.110	-0.506
Tilapia	0.372	-0.047	-0.005	-0.088	-0.554	0.427	-0.963
Salmon	-0.102	0.024	0.011	-0.098	0.073	-0.468	-0.225
Shrimp	0.163	-0.013	0.002	0.062	-0.013	0.090	0.177

Table 5. Allais Coefficients

	Catfish(D)	Catfish(M)	Trout	Tuna	Tilapia	Salmon	Shrimp
Catfish (D)	-1	-0.3455	-0.3109	-0.9990	-0.5039	-0.9933	-0.9980
Catfish (M)		-1	0.0000	-0.7659	-0.7727	-0.7406	-0.7773
Trout			-1	-0.6060	-0.5897	-0.5932	-0.6080
Tuna				-1	-0.9615	-0.9950	-0.9998
Tilapia					-1	-0.9444	-0.9648
Salmon						-1	-0.9940
Shrimp							-1

Table 6. Quantity and Scale Elasticity Coefficients and Exchange Rate Coefficients

	$dlnq_1$	$dlnq_2$	$dlnq_3$	$dlnq_4$	$dlnq_5$	$dlnQ$	$dlnE_{ca}$	$dlnE_{cb}$
D1	0.048***	-0.036***	0.001	-0.015***	0.003	0.050	0.109	-0.158**
M2		0.040***	-0.007	0.003	0.000	-0.062	-0.099	0.174**
M3			0.013**	-0.005*	-0.001	0.045	-0.071*	0.054*
M4				0.018***	-0.001	-0.018	0.078**	-0.079**
M5					0.000	-0.023	-0.007	-0.002

D1: Domestic Trout Budget Share
M2: Imported Frozen Fillet Budget Share
M3: Imported Fresh or Chilled Whole Trout Budget Share
M4: Imported Frozen Whole Trout Budget Share
q_1: Foodsize Domestic trout
q_2: Imported Frozen Fillet
q_3: Imported Fresh or Chilled Whole Trout
q_4: Imported Frozen Whole Trout
q_5: Imported Farm Raised Fresh Rainbow Trout
** represents statistical significant at 0.05 level
*** represents statistically significant at 0.01 level

Table 7. Compensated Quantity Elasticity and Scale Elasticity

	$dlnq_1$	$dlnq_2$	$dlnq_3$	$dlnq_4$	$dlnq_5$	$dlnQ$
D1	-0.094	0.029	0.034	0.009	0.022	-0.941
M2	0.342	-0.367	-0.068	0.074	0.019	-1.868
M3	0.867	-0.149	-0.575	-0.128	-0.015	0.376
M4	0.291	0.194	-0.153	-0.312	-0.019	-1.673
M5	1.004	0.074	-0.025	-0.028	-0.992	-2.203

Table 8. Uncompensated Quantity Elasticity

	$dlnq_1$	$dlnq_2$	$dlnq_3$	$dlnq_4$	$dlnq_5$
D1	-0.894	-0.039	0.003	-0.016	0.005
M2	-1.244	-0.501	-0.130	0.023	-0.016
M3	1.187	-0.122	-0.563	-0.118	-0.007
M4	-1.129	0.074	-0.208	-0.358	-0.051
M5	-0.867	-0.084	-0.097	-0.088	-1.034

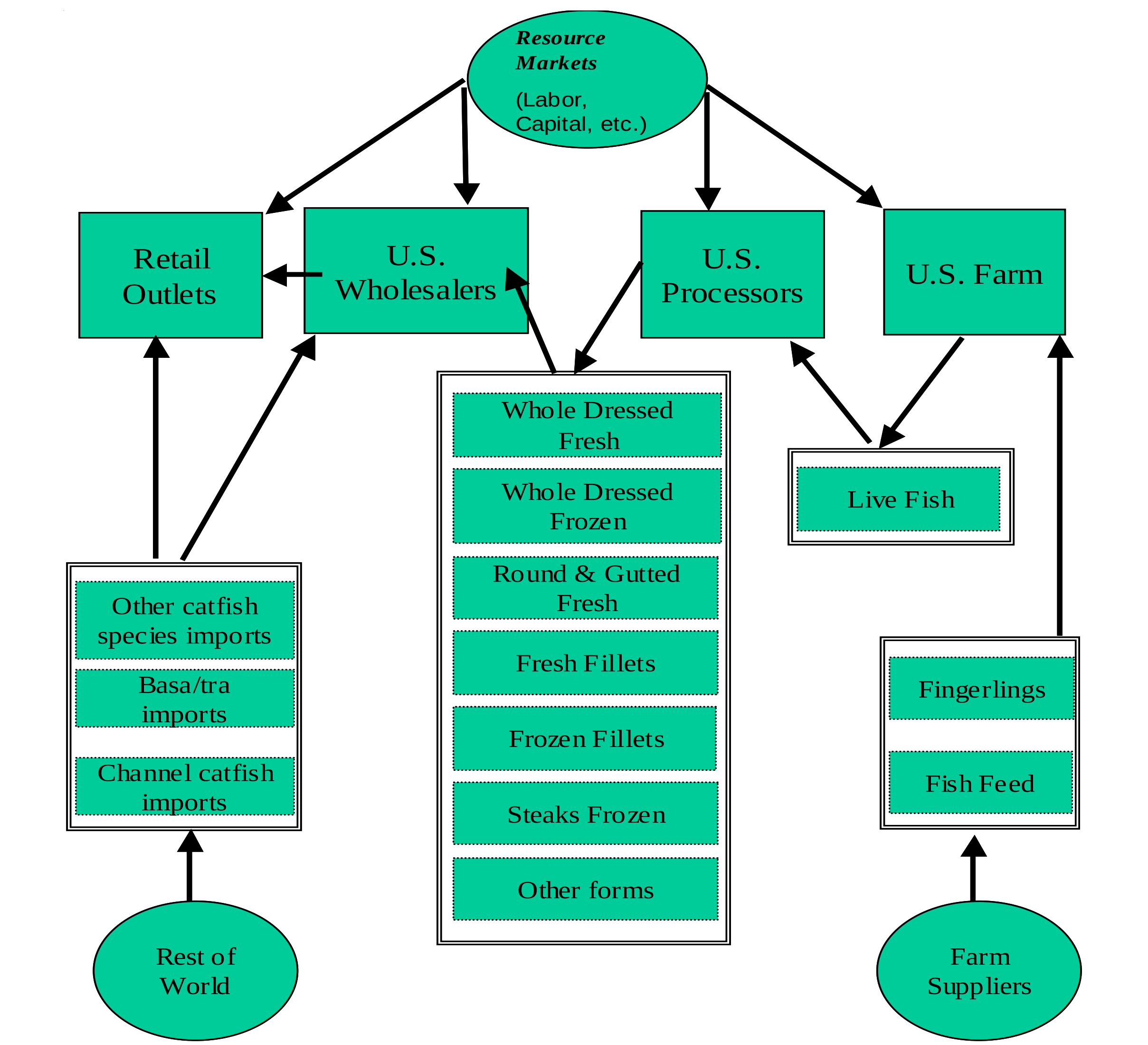
Table 9. Allais Coefficients

	$dlnq_1$	$dlnq_2$	$dlnq_3$	$dlnq_4$	$dlnq_5$
D1	-1	-0.882	0.000	-0.838	-0.624
M2		-1	-0.208	-0.223	-0.219
M3			-1	-0.380	-0.111
M4				-1	-0.176
M5					-1

Objective 1c. *Identify, develop, and validate economic forecasting models of catfish and trout: potential effects of various policy alternatives and external economic shocks*

University of Arkansas at Pine Bluff. A model for the catfish market in the U.S. (known as US-Catfish Model) was developed following a three-step procedure: 1) development of a baseline model, 2) estimation of behavioral systems and parameterization of equations, and 3) impact analysis under alternative policy scenarios. Figure 1 presents a graphical overview of catfish supply and distribution in the USA that is the basis for the US-Catfish Model developed by the UAPB team.

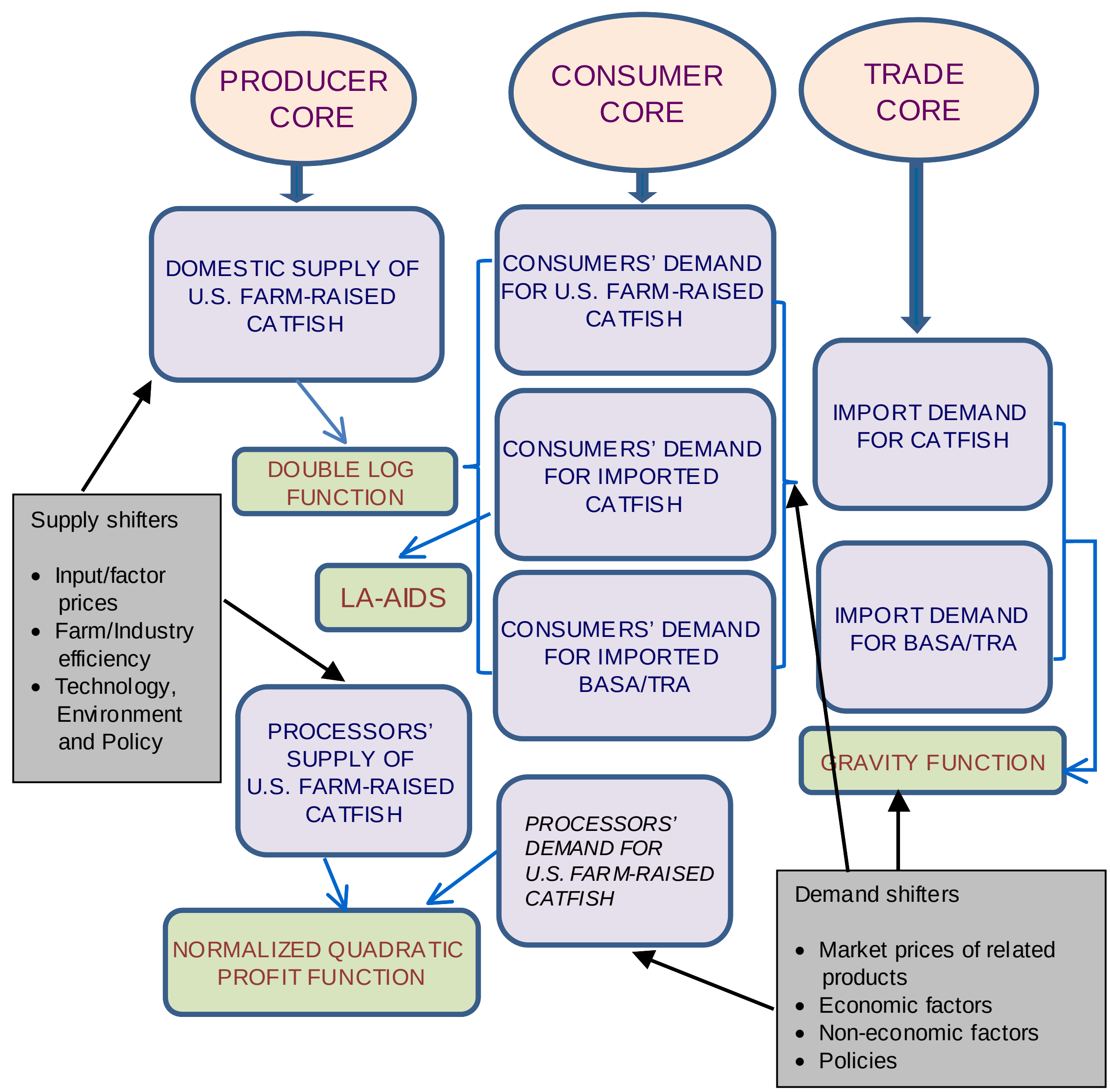
Figure 1. Overview of Catfish Industry Supply and Distribution in U.S.



Development of a baseline model

Figure 2 presents a schematic summary of the model structure and Appendix B provides the detailed model equations (along with parameters), model identities containing equilibrium conditions, and model closure. The model differentiates among U.S. farm-raised catfish, imported channel catfish, and imported basa and tra. The baseline model consists of a) producer core, b) consumer core, c) trade core, and d) model identities. The model provides links between technology, policy

Figure 2. Model Structure



and the market. The producer core represents domestic supply of U.S. farm-raised catfish, and catfish processors' supply of different U.S. farm-raised catfish products. The model assumes negligible landings of catfish (capture catfish) in the U.S. Meanwhile the consumer core deals with consumer demand for U.S. farm-raised catfish, imported channel catfish and imported basa/tra, and processors' demand for live U.S. farm-raised catfish (i.e., main input for catfish processing industry). The trade core incorporates imports and exports. The imports are related to the non-domestic supply made available to the U.S. market, and the exports are related to the non-domestic market destinations for U.S. produced goods. The present model assumes negligible exports of U.S. farm-raised catfish products. Finally, the model identities describe the price setting and market clearing conditions. The model is solved in 'Microsoft Office Excel Solver' by equating aggregate demand for and supply of farm-raised catfish, imported catfish and imported basa/tra with adjustment in prices subject to satisfying model identities and non-negativity restrictions.

Estimation of behavioral systems

Producer core. The producer core consists of the supply equation for U.S. farm raised catfish, and supply equations of processed products. The catfish processing industry uses joint inputs and produces multiproduct. Therefore, we have employed 'normalized quadratic profit function' to derive supply equations for processed products. This approach is widely used in cases of joint agricultural production. Estimation is undertaken here using the 'dual' approach, which is becoming the preferred method when sufficient price data are available. It is particularly appropriate for multi-output, joint-input productionsuch as capture fisheries.

In the baseline model, it is assumed that technology and policy can be modeled as a proportional and factor-neutral shift in quantity. For a given supply function, this may be represented as a distinction between actual and effective prices. The effective price method is fairly flexible in representing a variety of changing supply conditions.

Consumer core. The consumer core consists of processors' demand equation for inputs and consumers' demand for catfish. The processors' demand equation for inputs (live fish) has been derived from the 'normalized quadratic profit function'.

We have used the Almost Ideal Demand System (AIDS) to obtain consumer demand equations (in share forms) for U.S. farm-raised catfish, imported channel catfish and imported basa/tra.

Trade core. We have used an augmented gravity model (Anderson and Wincoop, 2003, American Economic Review 93(1):170-193) from a general equilibrium model. This model differs from commonly used gravity models by including 'multilateral resistance' terms capturing the country i's and country j's resistance to trade with all regions. These variables measure bilateral trade barriers in relation to trade barriers with other trading partners. However, the multilateral resistance terms are not observable. We, therefore, have used exporter and importer fixed effects as proxies of the multilateral resistance terms. Including these fixed effects also allows asymmetric trade flows with symmetric trade barriers, allowing a better fit with the data.

Model identities

Model identities describe the price setting and market clearing conditions. These consist of price transmission functions, relationship between different variables and equilibrium conditions.

Parameterization of equations. The parameterization approach was used to estimate the relevant coefficients of the behavioral equations presented in Appendix B. Initially, we had estimated the demand, supply and trade elasticities using the approaches discussed in the earlier section. Most of the estimated elasticities yielded satisfactory plausible values for the policy analysis. However, some of the elasticities were borrowed from earlier studies. Once obtained, these elasticities were transformed to suit the specification of the equations in the model. The intercept terms of all the relevant equations were then calibrated to ensure that the model replicated the baseline values. The preliminary results of the policy simulation exercise were discussed with different stakeholders in various conferences, and some of the elasticities and variables in the model were readjusted.

Impact analysis under alternative policy scenarios

To carry out the impact analysis under alternative policy scenarios, we constructed a numerical version of the model. We assembled a baseline data set (endogenous and exogenous variables) consistent with equilibrium conditions for the endogenous variables. Then, we obtained the elasticities (for some equations borrowed from other studies and for others we derived own estimates) and adjusted them on a priori grounds to meet the model conditions/restrictions. Accordingly, we derived the parameters (except intercept) of the model equations and calibrated the model equations to obtain the intercept so that the baseline data meet the equilibrium conditions.

We have carried out simulations to see the likely impact of changes in catfish feed price, The Catfish Institute (TCI) advertisement expenditure (for promoting U.S. farm-raised catfish), antidumping tariff levels imposed by U.S. on basa/tra imported from Vietnam, and U.S. per capita income. We have also analyzed the effects of 'Country of Origin Leveling' (COOL). Table 10 presents the results of these simulations on supply and demand for U.S. farm-raised catfish, imported channel catfish, and imported basa/tra. Table 11 details changes in surplus of U.S. consumers, farmers and processors, and channel catfish and basa/tra exporters to U.S.

Cost of feed contributes between 44 to 47% to the variable cost of production of catfish in the U.S. The average price of feed from 1987 to 2006 was $232 a ton, which climbed to an average level of $277 a ton in 2007 and soared to an average of $380 a ton for January and February, 2008. Corn and soybeans (main constituents of catfish feed) have nearly tripled in price in the last two years, for many reasons: harvest shortfalls, increasing demand by the Asian

Results at a glance...

Model results show the following effects:

- *A decrease in feed price would benefit the U.S. farm-raised catfish industry by reducing the price of domestically produced catfish, thereby increasing consumer demand.*
- *Increased TCI expenditures would benefit U.S. farm-raised catfish marginally, but would hurt imports significantly.*
- *Tariffs on imports increase U.S. wholesale prices by $0.07/pound and farm prices by $0.03/pound.*
- *Increased tariffs on Vietnamese basa and tra may enhance importation of channel catfish from China without substantially increasing the demand for U.S. farm-raised catfish.*
- *Increased U.S. per capita income would positively impact the catfish industry as a whole, with greater positive impacts on imported channel catfish and imported bas and tra.*
- *Country-of-origin-labeling has benefitted U.S. farm-raised catfish marginally, but has hurt channel catfish imports significantly.*

Table 10. Likely Impact of Change in Policy Variables on Demand for and Supply of Catfish and Basa/tra

(% change)

Policy Variable →	Base Line ('000 lb)	Feed Price		TCI Advert. Expenditure		Vietnam Tariff		US per Capita Income (2000=100)		COOL
Change over Base Line →		-15%	-25%	15%	25%	15%	25%	-10%	10%	
U.S. Farm-raised Catfish	34,601	1.82	2.51	5.59	8.66	-0.87	-1.58	-3.54	2.38	9.01
Imported Channel Catfish	904	0.45	0.62	-6.21	-9.87	1.07	1.64	-13.63	13.52	-15.70
Imported Basa/tra	3,812	1.04	1.44	-13.86	-21.28	-10.25	-15.94	-15.57	16.43	-5.42
Base line		$285/ton		$924,980		30%		127.43		

Table 11. Likely Impact of Change in Policy Variables on Consumer, Producer and Exporters' Surplus

Policy Variable →	Feed Price		TCI Advert. Expenditure		Vietnam Tariff		US per Capita Income (2000=100)		COOL
% Change in ↓	-15%	-25%	15%	25%	15%	25%	-10%	10%	
U.S. Surplus									
Consumers' Surplus	-0.13	-21.53	0.61	1.06	0.36	0.64	-5.43	3.71	13.51
Farmers' Surplus	-12.25	0.65	8.79	13.72	-1.34	-2.43	0.51	-0.68	13.60
Processors' Surplus	0.47	1.03	0.26	0.33	0.25	0.35	-15.33	15.87	-5.75
Total U.S. Surplus	**-11.91**	**-19.85**	**9.66**	**15.12**	**-0.73**	**-1.44**	**-20.24**	**18.89**	**21.96**
Surplus of Exporting Countries to U.S.									
Catfish Exporters Surplus	0.75	0.98	-7.03	-11.13	1.61	2.46	-7.96	6.81	-17.82
Basa/tra Exporters Surplus	0.71	0.98	-6.92	-11.19	-4.83	-7.82	-7.96	6.81	-75.57

middle class, and government mandates for corn to produce ethanol. Table 10 shows that a decrease in feed price would benefit the U.S. farm-raised catfish industry along with marginal gains to imported channel catfish and basa/tra. The decrease in feed price will lower the cost of production, which in turn increases the profitability of farmers, and hence increased supply. This will lower the domestic price of U.S. farm-raised catfish (processed), thereby, increasing the demand for the same. Market competition may cause a decline in import prices, and hence, may increase import demand to some extent.

On the other hand, an increase in TCI expenditures would benefit U.S. farm-raised catfish marginally; however, it would hurt imports significantly. Table 10 further shows that imported channel catfish would benefit more than U.S. farm-raised catfish with an increase in tariff levels on basa/tra imported from Vietnam. Increase in U.S. per capita income would have a positive impact on the catfish industry as a whole, with a greater positive impact on imported channel catfish and imported bas/tra. The results of the model further showed that COOL has benefitted U.S. farm-raised catfish marginally, but has hurt channel catfish imports significantly. COOL has resulted in an increase in U.S. consumers and farmers' surplus; however, U.S. processors' surplus have declined marginally (Table 11).

Objective 2. *Identify data needs necessary to refine the models for these species and to potentially apply to other species.*

All Project Participants. Data required for the demand and supply models include: quantities and prices of production inputs (feed ingredients, fuel, and electricity), prices and quantities of raw products used in the manufacture of production inputs, price and quantity of domestic product, and prices and quantities of competing products.

Data requirements for the international trade model are monthly domestic price and quantity data. These data are required for a number of years. Generally, the more years of data available, the more accurate the results. Data are required not only for the species in question, but also for the major substitute products.

Availability of Data for Catfish and Trout

- Detailed Data required for the catfish models are available in various published sources.
- Some of the data required for the trout model (for example, data on U.S. trout production and value by size and state) are available from 1989-2008.
- Data on trout processing (e.g. weight processed, processed weight sold, prices paid to producers, prices received by processors, etc.) are not available. The relevant agencies (including USDA) need to initiate collection of these data for trout and other aquaculture industries for required and meaningful policy analysis.

Objective 3. *Identify an industry-input framework to ensure model applicability.*

Meetings have been held with representatives of the catfish industry and preliminary meetings have been scheduled with representatives of the trout industry.

To date, the meetings with catfish farmers resulted in a list of issues and policy options to be considered in the policy analysis.

WORK PLANNED

- Development of the demand and supply models for trout.
- Development of an economic forecasting and policy analysis model of trout for potential effects of various policy alternatives and external economic shocks on the U.S. trout industry.
- Sharing the model framework and preliminary results with various stakeholders in various forums (including WAS 2010 in San Diego, Catfish Farmers of Arkansas meeting in Hot Springs, AR).

IMPACTS

- Models of demand and supply and international trade effects of catfish have been developed.
- We have shared some of the results of the policy analysis with congressional offices at their request and also with a number of catfish farmers. Hopefully, these outputs will contribute towards improving the competitiveness of U.S. catfish industry.

PUBLICATIONS

Dey, Madan M., Kehar Singh, Carole Engle and Abed Rabbani (2009). Analysis of catfish supply, demand and trade in USA: baseline model, estimation strategy and preliminary results. Page 365, Aquaculture America 2009 - Meeting Abstract, Seattle, Washington (U.S.).

Dey, Madan M., Kehar Singh and Carole Engle (2009). Analysis of catfish supply, demand and trade in USA: baseline model, estimation strategy and preliminary results. Paper presented at the forth forum of the North American Association of Fisheries Economists, May 17-20, 2009, Newport, Rhode Island (U.S.).

Dey, Madan M (2009). Food safety standards and U.S.-Asia aquaculture trade: applications of disagregated fish sector models. Presentation at the International Food Policy Research Institute (IFPRI), Washington DC, August 3, 2009.

Neal, S. J. 2008. The Impact of Imported Catfish on U.S. Wholesale and Farm Sectors. Master's Thesis, Department of Agricultural Economics, Mississippi State University.

◆ ◆ ◆

Appendix A

The Impact of Catfish Imports on the U.S. Wholesale and Farm Sectors
Model of the U.S. catfish industry

Following Crutchfield (1985) and Marsh (2003), a multi-level market model is developed to assess the impacts of imports on domestic catfish supply and demand at the wholesale/processor and farm levels. The structural model expressed in general notation for the U.S. catfish industry is as follows:

(1) Wholesale demand: $QW_D = \Psi_D(QW_D(-1)\ PW, PMC, PMT, PR, PE)$
(2) Wholesale supply: $QW_S = \Psi_S(QW_S(-1)\ PW, PF, PE)$
(3) Farm demand: $QF_D = \vartheta_D(QF_D(-1)\ PF, PW, PE)$
(4) Farm supply: $QF_S = \vartheta_S(QF_S(-1)\ PF, PE, PFD(-24))$
(5) Market clearing: $QW_D = QW_S = QW$
(6) Market clearing: $QF_D = QF_S = QF$

Equation (1) is catfish demand at the wholesale level which is the demand for processed catfish. Wholesale demand is a function of processor prices (*PW*), catfish import prices (*PMC*), tilapia import prices (*PMS*) a substitute for catfish, catfish prices at the retail level (*PR*), and energy prices (*PE*). Catfish supply at the wholesale level, equation (2) is also a function processor prices, but is also determined by the price of catfish at the farm level (*PF*) and energy prices. Catfish demand at the farm level, equation (3), is determined by the price of catfish at the farm level, processor prices, and energy prices. Catfish supply at the farm level, equation (4), is a function of prices at the farm level and energy prices, and the price of catfish feed (*PFD*). Note that the production period for catfish is about 2 years. Therefore, we assume that it is past feed prices that impact present quantity supplied. Equations (5) and (6) are the market clearing conditions. Equations (1) – (4) include lag dependent variables to account for dynamic or partial adjustments in farm and wholesale quantities.

Given the market clearing conditions, equations (1) – (4) form a system of four equations with four endogenous variables: *QW*, *QF*, *PW* and *PF*. Assuming linear functional forms, the system is restated as

(7a) $QW = a_0' + a_1 PW$

(7b) $QW = b_0' + b_1 PW + b_2 PF$

(7c) $QF = c_0' + c_1 PF + c_2 PW$

(7d) $QF = d_0' + d_1 PF$

where the intercept terms are linear combinations of the exogenous variables. For instance, in equation (7a) the intercept is

(8) $a_0' = a_0 + a_2 QW(-1) + a_3 PMC + a_4 PMT + a_5 PR + a_6 PE$

Setting equation (7a) equal to (7b), and (7c) equal to (7d), we get

(9) $$PW = \frac{b_0' - a_0'}{a_1 - b_1} + \frac{b_2}{a_1 - b_1} PF$$ and

(10) $$PF = \frac{d_0' - c_0'}{c_1 - d_1} - \frac{c_2}{c_1 - d_1} PW \, .$$

Thus the wholesale price at market clearing is

(11) $$PW^* = \frac{\dfrac{b_0' - a_0'}{a_1 - b_1} + \dfrac{b_2}{a_1 - b_1}\left(\dfrac{d_0' - c_0'}{c_1 - d_1}\right)}{1 + \dfrac{b_2}{a_1 - b_1}\left(\dfrac{c_2}{c_1 - d_1}\right)}$$

and the farm price at market clearing is

(12) $$PF^* = \frac{d_0' - c_0'}{c_1 - d_1} - \frac{c_2}{c_1 - d_1} PW^*$$

Substituting PW^* and PF^* into equations (7A) and (7D), respectively, the equilibrium quantities are

(13) $$QW^* = a_0' + a_1 PW^*$$

(14) $$QF^* = d_0' + d_1 PF^* .$$

From equations (11) – (14) it can easily be shown that import prices would effect domestic prices and quantities at both the wholesale and farm level since *QW*, *QF*, *PW* and *PF* are all either directly and/or indirectly determined by the value of a_0'. For instance, the impact of catfish imports prices on the domestic wholesale price and quantity is

(15) $$\frac{\partial PW^*}{\partial PMC} = \left[\frac{\dfrac{-a_3}{a_1 - b_1}}{1 + \dfrac{b_2}{a_1 - b_1}\left(\dfrac{c_2}{c_1 - d_1}\right)} \right]$$

(16) $$\frac{\partial QW^*}{\partial PMC} = \frac{\partial a_0'}{\partial PMC} + a_1 \frac{\partial PW^*}{\partial PMC} = a_3 + a_1 \left[\frac{\frac{-a_3}{a_1 - b_1}}{1 + \frac{b_2}{a_1 - b_1}\left(\frac{c_2}{c_1 - d_1}\right)} \right]$$

Empirical Results

The system of supply and demand equations (1) – (6) was estimated simultaneously using the full information maximum likelihood (FIML) procedure in TSP, version 5.0. Linear functional forms were assumed for each equation. Monthly data was used in estimating the model and the time period for the data was from January 1993 to December 2007. Domestic catfish quantities and prices were provided by the National Agricultural Statistic Service. Import prices were provided by the National Marine Fisheries Service. An energy price index was used as a proxy for energy cost, and the seafood retail price index was used as a proxy for catfish prices at the retail level. Both were provided by the Bureau of Labor Statistics.

Quagrainie et al. (2002) indicates that there is a positive price transmission between the price of domestic frozen fillets and the price of imported fillets. Therefore, catfish import prices may not be exogenous. To account for the endogeneity of catfish import prices, we estimated the following equation,

$$PMC_t = \alpha_0 + \alpha_1 PR_t + \alpha_3 PMT_t + \alpha_4 PE_t + \alpha_5 PFD_{t-24} + \alpha_6 t + \sum_{i=1}^{3} \delta_i Di_t + \varepsilon_t$$

and obtained the fitted values. The fitted values were then used as an instrument for actual import prices when estimating the model. To account for seasonal variation in catfish supply and demand, quarterly dummy variables were added to the model where *Di* was one in quarter *i* and zero otherwise. To account for technological change and other trending factors, trend terms (*t*) were added to the model.

The estimation of farm supply prove difficult in preliminary analysis, this may be due to the dynamic nature of catfish supply making it difficulty to obtain true farm supply determinants. Instead of estimating farm supply and demand directly, we imposed the market clearing condition at the farm level and estimated the following simultaneous system:

(17a) $$QW_t = a_0 + a_1 QW_{t-1} + a_2 PW_t + a_3 PR_t + a_4 PMC_t^p + a_5 PMT_t + a_6 PE_t + \sum^{3} \delta_i^a Di_t + \mu_t$$

(17b) $$QW_t = b_0 + b_1 QW_{t-1} + b_2 PW_t + b_3 PF_t + b_4 PE_t + b_5 t + \sum_{i=1}^{3} \delta_i^b Di_t + \upsilon_t$$

(17c) $$PF_t = c_0 + c_1 PW_t + c_2 PE_t + c_3 PFD_{t-24} + c_4 t + \nu_t \, .$$

Since equation (17c) is the empirical specification of equation (10) in the previous section, it is possible to assess the impact of import prices on farm prices; however, this specification does not allow for determining the equilibrium quantity and welfare at the farm level.

Table 1. Full-information maximum likelihood estimates

Model / Variable	Estimate	t-stat	
Wholesale Demand *(QW_D)*			
constant	18,200.80	3.91	**
QW_D (-1)	0.401	5.82	**
PW	-8,169.13	-4.21	**
PR	65.68	3.74	**
PMC	1,879.00	2.28	*
PMT	1,498.44	1.79	
PE	-1,080.01	-1.95	
*D*1	3,341.74	9.64	**
*D*2	993.12	2.56	**
*D*3	1,523.43	4.50	**
Wholesale Supply *(QW_S)*			
constant	-8,016.96	-0.67	
QW_S (-1)	0.561	8.42	**
PW	16,502.80	1.64	
PF	-26,971.20	-1.65	
PE	-3,024.65	-2.76	**
trend	2,880.44	2.38	*
*D*1	3,146.59	8.18	**
*D*2	-38.17	-0.10	
*D*3	1,274.13	3.47	**
Farm Price *(PF)*			
constant	-0.391	-3.73	**
PW	0.450	7.99	**
PE	0.037	1.66	
PFD(-24)	0.754	3.05	**
trend	-0.063	-2.78	**

** Significant at the 0.01 level.
* Significant at the 0.05 level.
Wholesale demand: R^2 = 0.749; Durbin-w = 2.340; Durbin-h = 3.598.
Wholesale supply: R^2 = 0.574; Durbin-w = 2.024; Durbin-h = 0.235.
Farm price: R^2 = 0.847; Durbin-w = 1.228;

Table 2. Short- and long-run wholesale demand and supply elasticities

	Short-run		Long-run	
% Δ in QW_D w.r.t.	Estimate	t-stat	Estimate	t-stat
Own-price	-0.80	-4.21**	-1.33	-5.57 **
Retail fish index price	0.45	3.74**	0.75	4.18 **
Imported catfish price	0.11	2.28*	0.18	2.43 *
% Δ in QW_S w.r.t.				
Own-price	1.61	1.64	3.66	1.49
Farm price	-0.82	-1.65	-1.86	-1.51
Energy price index	-0.18	-2.76**	-0.41	-2.64 **

Table 3. Impact of the tariff on the U.S. catfish industry

	Baseline (equilibrium)	Tariff	Difference	% change
Wholesale Quantity (1,000 lb)	23,670.09	23,984.79	314.70	1.33
Wholesale Price ($/lb)	2.30	2.37	0.07	3.13
Farm price ($/lb)	0.72	0.75	0.03	4.52
Welfare				
Consumer Surplus ($1,000)	34,292.08	35,209.99	917.91	2.68%
Processor Surplus ($1,000)	25,630.42	26,834.95	1,204.53	4.70%
Total ($1,000)	59,922.50	62,044.94	2,122.44	3.54%
Revenue				
Processor ($1,000)	54,466.80	56,918.49	2,451.68	4.50
Farm ($1,000)	33,965.52	35,971.43	2,005.92	5.91

Appendix B

US Catfish Model: Equations and Identities

A. Model Development

The producer core consists of the supply equation for U.S. farm raised catfish, and supply equations of processed products. We have used double log function to represent the supply U.S. farm raised catfish:

$$\ln\left(Q_{frCatfish}^{FS-dom}\right) = \alpha_0^{FS-dom} + \alpha_1^{FS-dom} \times \ln(P_{frCatfish}^{PBP}) + \sum_{i=1}^{n} \beta_i^{FS-dom} \times \ln(P_i^{dom})$$

$$Where, P_i^{dom} \quad is \quad the \quad factor \quad prices \quad (fingerlings, feed, fuel, electricity, wage)$$

The catfish processing industry uses joint inputs and produces multiproduct. Therefore, we have employed 'normalized quadratic profit function' to derive supply equations for processed products. This approach is widely used in cases of joint agricultural production (e.g., Shumway *et al.*, 1987; Ball *et al.*, 1997). Estimation is undertaken here using the 'dual' approach, which is becoming the preferred method when sufficient price data are available (Jensen, 2003). It is particularly appropriate for multioutput, joint input production, e.g., Squires (1987), Kirkley and Strand (1988), and others have applied it to capture fisheries. Dey *et al.* (2005) have applied this approach in AsiaFish Model. The 'normalized quadratic profit function' is given as follows:

$$\pi = \alpha_0 + \sum_{i=1}^{m-1} \beta_i P_i + \sum_{i=m+1}^{n} \gamma_i X_i + \tfrac{1}{2}\left(\sum_{i=1}^{m-1}\sum_{j=1}^{m-1} \beta_{ij} P_i P_j + \sum_{i=m+1}^{n}\sum_{j=m+1}^{n} \gamma_{ij} X_i X_j \right) + \sum_{i=1}^{m-1}\sum_{j=m+1}^{n} \lambda_{ij} P_i X_j + e_i$$

Where, π is the normalized profit (normalized by P_m) evaluated at the optimum, P_is are output and input prices normalized by P_m, X_i is a vector of variables on technology, environment, policy and fixed inputs, e_i is the error term, and α, β, γ, and λ are the parameters of the equation. Then by the 'envelope theorem', the output supply of i[th] product is:

$$\frac{\partial \pi}{\partial P_i} = X_i = \beta_i + \sum_{j=1}^{m-1} \beta_{ij} P_j + \sum_{j=m+1}^{n} \lambda_{ij} X_j + e_i$$

To derive the supply of the numeraire, multiply the expression in (…) by P_m to obtain normal profit; differentiating by P_m yields:

$$QNUM = \alpha_0 ` + \sum_{i=m+1}^{n} \gamma_i X_i - \tfrac{1}{2} \sum_{i=-}^{m-i}\sum_{j=1}^{m-1} \beta_{ij} P_i P_j + \tfrac{1}{2} \sum_{i=m+1}^{n}\sum_{j=m+1}^{n} \gamma_{ij} X_i X_j + e_i$$

The derivation of the supply functions from a profit function entails certain restrictions on the former. A profit function is homogenous of degree one in prices, and should have equal cross-price derivatives; hence, the supply parameters must conform to a homogeneity and symmetry restriction. Homogeneity is already incorporated by normalization, while symmetry can be implemented by imposing $\beta_{ij} = \beta_{ji}$ during estimation.

In the baseline model, it is assumed that technology and policy can be modeled as a proportional and factor-neutral shift in quantity. For a given supply function, this may be represented as a distinction between actual and effective prices (see Alston *et al.*, 1995 and Dey *et al.*, 2005). The effective price method is fairly flexible in representing a variety of changing supply conditions.

Consumer core

The consumer core consists of processors' demand equation for inputs and consumers demand for catfish. The processors' demand equation for inputs (live fish) has been derived from 'normalized quadratic profit function' given as follows:

$$\frac{\partial \pi}{\partial P_j} = -X_i = \beta_i + \sum_{j=1}^{m-1} \beta_{ij} P_j + \sum_{j=m+1}^{n} \lambda_{ij} X_j + e_i$$

We have used Almost Ideal Demand System (AIDS) to obtain consumers demand equations (in share forms) for U.S. farm-raised catfish, imported channel catfish and imported basa/tra.

$$w_i = \alpha_i^{CD} + \sum_i \beta_i^{CD} \times \ln(P_i) + \gamma^{CD} \times \ln(X/P) + \sum_j \varphi_j^{CD} X_j + e_{ij}$$

Where, w and P are the expenditure share and price of the products, respectively. X is the vector of exogenous variables, X/P is the real expenditure of the consumers, e is the error term, and α, β, γ and φ are the parameters of the model.

The consumers' demand for i[th] product has been obtained from share equations as follows:

$$Q_i^{CD-dom} = w_i \times \frac{\sum_i p_i q_i}{P_i}, \textit{where } \sum_i p_i q_i \textit{ is the total expenditure.}$$

Trade core

We have used an augmented gravity model derived by Anderson and Wincoop (2003) from a general equilibrium model. This model differs from commonly used gravity models by including 'multilateral resistance' terms capturing the country i's and country j's resistance to trade with all regions. These variables measure bilateral trade barriers in relation to trade barriers with other trading partners. However, the multilateral resistance terms are not observable. We, therefore, have used exporter and importer fixed effects as proxies of the multilateral resistance terms (Anderson and Wincoop, 2003). Including these fixed effects also allows asymmetric trade flows with symmetric trade barriers, allowing a better fit with the data (Kupier and Tongeren, 2006). The augment gravity model is specified as follows:

$$\ln(Q_i^{S-imp}) = \rho_k + \rho_j + \varphi^{S-imp} + \sum_{i=1} \gamma_i^{dom} \ln(P_i) + \sum_m \gamma^m \ln(\text{EconV}) + \sum_n \gamma^n \ln(\text{NEconV}) + \sum_o \gamma^o \ln(\text{PolV}) + e_i$$

Where,

ρ 's are multilateral resistance terms (exporter and importer fixed effects); Subscript 'i', 'j' and 'k' denote the product (imported channel catfish and basa/tra), the exporting country, and the importing country (in our case U.S.), respectively; 'P_i' represents price of i^{th} product which include competing products; e_i is the error term; and γ and φ are the parameters of the model; EconV and NEconV signify economic variables (like gross domestic product, population, x-rates) and non-economic variable capturing cultural and political distances, respectively, effecting trade; and PolV denotes policy variable like promotional activities, antidumping measures, tariffs, etc.

Model identities

Model identities describe the price setting and market clearing conditions. These consist of price transmission functions, relationship between different variables and equilibrium conditions.

Parameterization of equations

The parameterization approach was used to estimate the relevant coefficients of the behavioral equations. Initially, we had estimated the demand, supply and trade elasticities using the approached discussed in the earlier section. Most of the estimated elasticities yielded satisfactory plausible values for the policy analysis. However, some of the elasticities were borrowed from earlier studies. Once obtained, these elasticities were transformed to suit the specification of the equations in the model. The intercept terms of all the relevant equations were then calibrated to ensure that the model replicated the baseline values. The preliminary results of the policy simulation exercise were discussed with different stakeholders in various conferences, and some of the elasticities and variables in the model were readjusted.

B. Consumer Core

Expenditure Share Equations (LA-AIDS)

Expenditure Share Equation for U.S. Farm-Raised Catfish $\left(w_{Catfish}^{fr}\right)$:

$$CC(1) \qquad w_{Catfish}^{fr} = -2.7857 + 0.0260 \times \ln(P_{frCatfish}^{*dom}) + 0.0678 \times \ln(P_{Catfish}^{*imp})$$

$$+ 0.0509 \times \ln(P_{Basa/tra}^{*imp-world}) + 0.0743 \times \ln(P_{Tilapia}^{*imp})$$

$$+ 0.1095 \times \ln(X / P) + 0.2228 \times TCI + +0.0053 \times Pop_{US} + 0.0316 \times COOL$$

Expenditure Share Equation for Imported Catfish $\left(w_{Catfish}^{imp}\right)$:

$$CC(2) \qquad w_{Catfish}^{imp} = -0.1050 + 0.0037 \times \ln(P_{frCatfish}^{*dom}) - 0.0105 \times \ln(P_{Catfish}^{*imp})$$
$$+ 0.0039 \times \ln(P_{Basa/tra}^{*imp}) + 0.0028 \times \ln(P_{Tilapia}^{*imp})$$
$$+ 0.0020 \times \ln(X/P) + 0.0212 \times Pop_{US} - 0.0058 \times COOL$$

Expenditure Share Equation for Imported Catfish $\left(w_{Basa/tra}^{imp}\right)$:

$$CC(3) \qquad w_{Basa/tra}^{imp} = 0.0986 + 0.0068 \times \ln(P_{frCatfish}^{*dom}) + 0.0129 \times \ln(P_{Catfish}^{*imp})$$
$$- 0.0265 \times \ln(P_{Basa/tra}^{*imp}) + 0.0068 \times \ln(P_{Tilapia}^{*imp})$$
$$+ 0.0008 \times \ln(X/P) + 0.0015 \times Pop_{US} - 0.0520 \times COOL$$

Processors' Demand Equation (Normalized Quadratic Profit Function)

Processors' Demand for U.S. Farm-Raised Catfish $\left(Q_{frCatfish-\Pr ocessedWt}^{\Pr ocessorD}\right)$:

$$CC(4) \qquad Q_{frCatfish-\Pr ocessedWt}^{\Pr ocessorD} = \text{-}12543.5074 + 761.50 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} - 378.92 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}}$$
$$+ 144.03 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}} - 151.76 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} + 245.99 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} + 98.92 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$
$$+ 173.86 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 178.23 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 54337.78 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} + 1340.47 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$
$$+ 26.16 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} - 39062.02 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} - 1928.86 \times \frac{CPI - F \,\&\, Bev}{P_{steakFroz}^{PSP}}$$

C. Producer Core

Domestic Supply Equation for US Farm-Raised Catfish (Double log Function)

Supply of U.S. Farm-Raised Catfish $\left(Q_{frCatfish}^{S-dom}\right)$:

$$S(1) \quad \ln\left(Q_{frCatfish}^{FS-dom}\right) = 27.7737 + 1.8235 \times \ln(P_{frCatfish}^{PBP}) - 0.1500 \times \ln(P_{Fingerlings}^{dom}) - 1.7800 \times \ln(P_{Feed}^{dom}) - 0.1000 \times \ln(P_{Fuel}^{dom}) - 0.1000 \times \ln(P_{Electricity}^{dom}) - 5.0550 \times \ln(P_{WageRate}^{dom})$$

Processors' Supply Equations for Different Products (Normalized Quadratic Profit Function)

Processors' Supply of Round and Gutted Fresh $\left(Q_{R\&GFresh}^{ProcessorS}\right)$

$$S(2) \quad Q_{R\&GFresh}^{ProcessorS} = 1636.3838 + 101.2072 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} - 78.4819 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} - 135.0662 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}} + 117.8168 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} - 20.2359 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} + 10.8645 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 121.5899 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 243.8940 \times \frac{P_{frCatfish}^{PBP}}{P_{steakFroz}^{PSP}} + 9831.9593 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 329.7612 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}} - 110.8100 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 3871.2206 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} + 1878.2037 \times \frac{CPI - F \& Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Whole Dressed Fresh $\left(Q_{WhDressFr}^{ProcessorS}\right)$

$$S(3) \quad Q_{WhDressFr}^{ProcessorS} = 1407.1287 - 23.8473 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} + 52.6020 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} + 140.4788 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}} + 63.2134 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} - 140.8869 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 20.8239 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 41.3269 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 0.1876 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 10474.7926 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 82.5059 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}} + 104.4400 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 4538.9238 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} - 1336.3932 \times \frac{CPI - F \& Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Other Fresh $\left(Q_{OtherFr}^{ProcessorS}\right)$

$$S(4) \quad Q_{OtherFr}^{ProcessorS} = 499.7585 - 615.0150 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} + 723.0623 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} + 81.8293 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$-131.9244 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} - 190.8296 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 44.1848 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$-56.2260 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 225.4999 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 5004.8605 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} + 425.8890 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$

$$+113.4300 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} - 7129.9032 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} - 1592.4748 \times \frac{CPI - F \& Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Fillet Fresh $\left(Q_{FilletFr}^{ProcessorS}\right)$

$$S(5) \quad Q_{FilletFr}^{ProcessorS} = 4764.6845 + 35.3252 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} + 20.1131 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} - 65.4681 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+4.3712 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} + 38.1056 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} + 5.1619 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$-104.1733 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 157.1416 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 17516.3238 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 323.1987 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$

$$+204.5000 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 12035.0253 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} - 2059.9643 \times \frac{CPI - F \& Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Whole Dressed Frozen $\left(Q_{WhDressFroz}^{ProcessorS}\right)$

$$S(6) \quad Q_{WhDressFr}^{ProcessorS} = 1166.5806 - 128.7214 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} - 209.5112 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} - 71.6306 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+104.2277 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} + 23.1358 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 70.8024 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+71.1727 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 197.1554 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 9404.3915 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 153.5330 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$

$$+109.7000 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 4160.6802 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} + 1131.9325 \times \frac{CPI - F \& Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Other Frozen $\left(Q_{OtherFroz}^{ProcessorS}\right)$

$$S(7) \qquad Q_{OtherFr}^{ProcessorS} = 3058.2233 + 11.0722 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} - 48.1894 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} - 41.6692 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+17.5451 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} - 41.0994 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} + 13.0515 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+26.5325 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 185.5772 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 11065.7257 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 197.8075 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$

$$-106.6000 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 5329.7926 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} + 2341.1632 \times \frac{CPI - F\ \&\ Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Fillet Frozen $\left(Q_{FilletFroz}^{ProcessorS}\right)$

$$S(8) \qquad Q_{FilletFroz}^{ProcessorS} = 2119.2081 - 141.5231 \times \frac{P_{R\&GFr}^{PSP}}{P_{steakFroz}^{PSP}} - 80.6740 \times \frac{P_{WhDressFr}^{PSP}}{P_{steakFroz}^{PSP}} - 52.4991 \times \frac{P_{OtherFr}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$-23.4900 \times \frac{P_{FilletFr}^{PSP}}{P_{steakFroz}^{PSP}} + 85.8179 \times \frac{P_{WhDressFroz}^{PSP}}{P_{steakFroz}^{PSP}} + 7.8158 \times \frac{P_{OtherFroz}^{PSP}}{P_{steakFroz}^{PSP}}$$

$$+51.7524 \times \frac{P_{FilletFroz}^{PSP}}{P_{steakFroz}^{PSP}} - 775.1779 \times \frac{P_{RWP}^{dom}}{P_{steakFroz}^{PSP}} - 16517.6262 \times \frac{P_{Fuel}^{dom}}{P_{steakFroz}^{PSP}} - 264.6949 \times \frac{P_{Eletricity}^{dom}}{P_{steakFroz}^{PSP}}$$

$$-134.9900 \times \frac{P_{WageRate/hr}^{dom}}{P_{steakFroz}^{PSP}} + 12342.4342 \times \frac{GDP(2000=100)}{P_{steakFroz}^{PSP}} - 2252.9332 \times \frac{CPI - F\ \&\ Bev}{P_{steakFroz}^{PSP}}$$

Processors' Supply of Steak Frozen $\left(Q_{SteakFroz}^{ProcessorS}\right)$

$$S(9) \qquad Q_{SteakFroz}^{ProcessorD} = 35.3196 - 0.0967 \times \left(P_{R\&GFr}^{PSP} \times P_{frCatfish}^{PBP}\right) - 0.3667 \times \left(P_{WhDressFr}^{PSP} \times P_{frCatfish}^{PBP}\right)$$

$$-0.1410 \times \left(P_{OtherFr}^{PSP} \times P_{frCatfish}^{PBP}\right) + 1593 \times \left(P_{FilletFr}^{PSP} \times P_{frCatfish}^{PBP}\right)$$

$$+0.1609 \times \left(P_{WhDressFroz}^{PSP} \times P_{frCatfish}^{PBP}\right) + 0.00 \times \left(P_{SteakFroz}^{PSP} \times P_{frCatfish}^{PBP}\right) + 0.1818 \times \left(P_{OtherFroz}^{PSP} \times P_{frCatfish}^{PBP}\right)$$

$$-0.0321 \times \left(P_{FilletFroz}^{PSP} \times P_{frCatfish}^{PBP}\right) - 4.2696 \times P_{Fuel}^{dom} - 41.5902 \times P_{Eletricity}^{dom}$$

$$-12.2761 \times P_{WageRate/hr}^{dom} + 0.8932 \times GDP(2000=100) + 1.5572 \times CPI - F\ \&\ Bev$$

D. Trade Core

Trade Equations (Gravity Function)

Import Demand of Catfish from World $(Q_{catfish}^{imp-D})$

$$TC(1) \qquad \ln(Q_{catfish}^{imp-D}) = \text{-}12.5540 + 1.3933 \times \ln(P_{frCatfish}^{*dom}) - 0.5007 \times \ln(P_{catfish}^{*imp,world})$$
$$+ 0.1666 \times \ln(P_{basa/tra}^{*imp,world}) + 1.6888 \times \ln(US - GDP) + 0.9384 \times \ln(US - Pop)$$
$$+ 2.0700 \times \ln(X - rateChina) - 0.6082 \times \ln(TCI - AdvExp.)$$

Import Demand of Basa/tra from World $(Q_{basa/tra}^{imp-D})$

$$TC(2) \qquad \ln(Q_{basa/tra}^{imp-D}) = \text{-}21.7634 + 1.6442 \times \ln(P_{frCatfish}^{*dom}) + 0.8059 \times \ln(P_{catfish}^{*imp,world})$$
$$- 0.0872 \times \ln(P_{basa/tra}^{*imp,world}) + 1.4623 \times \ln(US - GDP) + 2.0422 \times \ln(US - Pop)$$
$$+ 1.1115 \times \ln(X - rateVietnam) - 0.9987 \times in(TCI - AdvExp.) - 0.7974 \times \ln(Tariff)$$

Model Identities

Consumers' demand for U.S. farm raised catfish (Processed Weight) $(Q_{frCatfish-ProcessedWt}^{CD-dom})$:

MI(1) $$Q_{frCatfish-ProceesedWt}^{CD-dom} = w_{frCatfish} \times \frac{\sum_{i=1}^{n} p_i q_i}{P_{frCatfish}^{*dom}}$$

Consumers' demand for imported catfish $(Q_{Catfish}^{CD-imp})$:

MI(2) $$Q_{Catfish}^{CD-imp} = w_{Catfish}^{imp} \times \frac{\sum_{i=1}^{n} p_i q_i}{P_{Catfish}^{*imp}}$$

Consumers' demand for imported basa/tra $(Q_{Basa/tra}^{CD-imp})$:

MI(3) $$Q_{Basa/tra}^{CD-imp} = w_{Basa/tra}^{imp} \times \frac{\sum_{i=1}^{n} p_i q_i}{P_{Basa/tra}^{*imp}}$$

Where,

'i' is U.S. farm-raised catfish, imported catfish, imported basa/tra, and imported tilapia.

Processors' Demand in Live Weight Equivalent $\left(Q^{ProcessorD}_{frCatfish-LiveWt}\right)$ and processed weight equivalent $\left(Q^{ProcessorD}_{frCatfish-ProWt}\right)$

MI(4) $$Q^{ProcessorD}_{frCatfish-LiveWt} = 1.9871 \times Q^{ProcessorD}_{frCatfish-ProWt}$$

Farmers' Total Supply (Live Weight) $\left(Q^{S-dom}_{frCatfish}\right)$ and Farmers' Supply to Processor (Live Weight) $\left(Q^{FS-Processor}_{frCatfish-LiveWt}\right)$:

MI(5) $$Q^{FS-Processor}_{frCatfish-LiveWt} = 0.95 \times Q^{S-dom}_{frCatfish}$$

Farmers' Total Supply (Live Weight) $\left(Q^{S-dom}_{frCatfish}\right)$ and Farmers' Supply to Others (Live Weight) $\left(Q^{FS-Others}_{frCatfish}\right)$:

MI(6) $$Q^{FS-Others}_{frCatfish} = 0.05 \times Q^{S-dom}_{frCatfish}$$

Aggregate Processors' Supply (Processed Weight) $\left(Q^{ProcessorS}_{ProcessedWt}\right)$:

MI(7) $$Q^{ProcessorS}_{ProcessedWt} = 1.2789 \times \sum_{j=1}^{n} Q^{ProcessorS}_{j} = \sum_{j=1}^{n} Q^{ProcessorS}_{j} + Q^{ProcessorS}_{Nuggets}$$

Where,

'j' represents processed products namely round and gutted fresh, whole dressed fresh, fillet fresh, other fresh, whole dressed frozen, fillet frozen, other frozen, and steaks frozen.

Consumers' Demand for Farm-raised Catfish in Live Weight Equivalent $(Q^{CD-dom}_{frCatfish-LiveWt})$ and Processed Weight $(Q^{CD-dom}_{frCatfish-ProcessedWt})$:

MI(8) $$Q^{CD-dom}_{frCatfish-LiveWt} = 1.9871 \times Q^{CD-dom}_{frCatfish-ProcessedWt}$$

Price Transmission Functions

Domestic price of farm raised catfish $\left(P^{*dom}_{frCatfish}\right)$ and average price received by processor $\left(P^{Processor}_{frCatfish}\right)$:

PT(1) $$P^{*dom}_{frCatfish} = P^{Processor}_{frCatfish}$$

Where

$$P^{Processor}_{frCatfish} = Average\ Price\ Received\ by\ the\ Processor$$

Model Closure

Equilibrium Between Consumers' Demand $\left(Q_{Basa/tra}^{CD-imp}\right)$ and Import Demand $\left(Q_{Basa/tra}^{imp-D}\right)$ for Basa/tra:

$$Q_{Basa/tra}^{imp-D} = Q_{Basa/tra}^{CD-imp}$$

Equilibrium Between Consumers' Demand $\left(Q_{Catfish}^{CD-imp}\right)$ and Import Demand $\left(Q_{Catfish}^{imp-D}\right)$ for Channel Catfish Imported:

$$Q_{Catfish}^{imp-D} = Q_{Catfish}^{CD-imp}$$

Farmers' Supply to Processor (Live Weight) $\left(Q_{frCatfish-LiveWt}^{FS-Processor}\right)$ and Processors' Demand in Live Weight Equivalent $\left(Q_{frCatfish-LiveWt}^{ProcessorD}\right)$

$$Q_{frCatfish-LiveWt}^{FS-Processor} = Q_{frCatfish-LiveWt}^{ProcessorD}$$

Market Equilibrium

$$Q_{frCatfish-ProcessedWt}^{ProcessorS} + Q_{Catfish}^{imp-D} + Q_{Basa/tra}^{imp-D} = Q_{frCatfish-ProcessedWt}^{CD-dom} + Q_{Catfish}^{CD-imp} + Q_{Basa/tra}^{CD-imp}$$

Adjustable Variable for Model Closure:

Domestic Price of U.S. Farm-raised Catfish $(P_{frCatfish}^{*dom})$, World Import Unit Value of Channel Catfish $(P_{Catfish}^{*dom})$, World Import Unit Value of basa/tra $(P_{Basa/tra}^{*dom})$, and Processors' sale price for j^{th} product ($P_{R\&GFr}^{j}$)

Where, 'j' represents processed products namely round and gutted fresh, whole dressed fresh, fillet fresh, other fresh, whole dressed frozen, fillet frozen, steaks frozen, and other frozen.

IMPROVING REPRODUCTIVE EFFICIENCY OF CULTURED FINFISH

Reporting Period
February 1, 2009 - August 31, 2009

Funding Level	Year 1	$222,633
	Year 2	$195,693
	Year 3	$78,456
	Total	$496,782

Participants	USDA/ARS Catfish Genetics Research Unit (Lead Institution)	Brian Small, Ken Davis, Les Torrans, Brian Bosworth, Geoff Waldbieser
	Texas A&M University at Corpus Christi	Paul Zimba
	Texas A & M University	Delbert Gatlin
	Auburn University	Allen Davis, Rex Dunham
	University of Florida	Cortney Ohs, Craig Watson
	University of Tennessee	Richard Strange
	University of Arkansas at Pine Bluff	Alf Haukenes, Rebecca Lochmann, Steve Lochmann
	USDA/ARS/Stuttgart National Aquaculture Research Center	Adam Fuller, Jerry Ludwig

Administrative Advisor
Dr. Jonathan Pote
Mississippi State University
Mississippi State, Mississippi

PROJECT OBJECTIVES

1. Improve broodfish management protocols for increased reproductive efficiency through:

    a. Developing pre-selection methods of potential broodfish to be included in the broodstock population.
    b. Improving conditioning and preparation of broodfish.
    c. Final identification of broodstock for spawning .

2. Improve spawning protocols to increase reproductive efficiency through:

    a. Managing spawning conditions.
    b. Improving the collection and handling of fertilized eggs.

ANTICIPATED BENEFITS

Captive-bred finfish rarely experience all aspects of natural spawning conditions, and thus dependence on natural reproduction is often unreliable. Consequently, reproductive efficiency is often less than desired, frequently requiring creative management or compensatory protocols to overcome the failure to reproduce spontaneously and at full potential. This project will improve reproductive efficiency of commercially cultured finfish of immediate importance to the Southern Region. Management protocols will be established that address reproductive bottlenecks and result in improved protocols that increase reproductive efficiency for the target species and have the potential for use with other similarly cultured finfish species.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. *Improve broodfish management protocols for increased reproductive efficiency*

Objective 1a. *Develop pre-selection methods of potential broodfish to be included in the broodstock population*

USDA-ARS Catfish Genetics Research Unit. The first year of spawning data (2008) for channel catfish has been collected and analyzed. A total of 194 spawns was collected and first and last spawns were collected on May 8 and August 18, respectively. Molecular marker genotypes were successfully used to assign parentage of spawns indicating that of 579 males stocked, 93 spawned, and 35 of those spawned more than once. Of 663 females stocked, 174 spawned, and 20 of those spawned more than once. Females that spawned were larger than females that did not spawn, but spawning and non-spawning males were not different in weight. Female spawning time and incidence were not different among farm of origin. Male incidence of spawning was not different among farm of origin, but time of male spawning was slightly different among farms. Family of origin did not affect spawning incidence of females, but did have an effect on spawning time. Family of origin affected incidence of spawning in males, and had a smaller effect on spawning time. Ultrasound estimates of ovary size (Figure 1) were

Figure 1. Ultrasound image of catfish ovary.

larger for spawning females than non-spawning females (2.96 cm^2 vs 2.58 cm^2) but the differences were likely too small to be useful for sorting fish to increase spawning. Estradiol and testosterone levels were not predictive of spawning success in males or females.

The second year of spawning data (2009) has been collected and is currently being analyzed to determine relationships between spawning success and the same factors studied in the first year. A total of 634 females and 368 males from the same population were stocked into ponds the spring of 2009. Three hundred sixty five spawns were collected in 2009, and the first and last spawns were collected on April 30 and August 5, respectively. Of the 368 males stocked, 147 spawned and 71 spawned more than once. Of the 634 females stocked, 318 females spawned, and 43 spawned more than once. Ultrasound and hormone data are currently being analyzed.

In a separate study, endocrine factors which determine sexual maturation in channel catfish were evaluated using fish held under a modified thermoperiod. Catfish held under a shortened annual temperature cycle of four months in 26 C water followed by two months in 13–14^{o}C water spawned at a higher rate (73%) after three temperature cycles than fish held in outdoor ponds on two normal seasonal temperature cycles (10%). These data suggest that the onset of the maturation leading to spawning is a developmental event that requires three cycles of warm and cold periods. Fish from both treatment groups (Cycled and Control) were sacrificed for quantification of circulating estradiol concentrations and mRNA concentrations of gonadotropin subunits (GTH-α, GTH-Iβ, and GTH-IIβ) and steroidogenic factor-1 isoforms (SF-1a and SF-1b) in the pituitary and ovary.

Among the measures of plasma steroid and tissue mRNA, only ovarian GTH-Iβ mRNA was significantly different between the two groups of fish and was elevated during May in the 2-year-old fish. In both groups of fish, measures of steroid and mRNA were lower in 2-year-old fish relative to concentrations in 3-year-old Control fish. In 3-year-old Control fish, SF-1a, GTH-α, GTH-Iβ, and GTH-IIβ were all elevated in spring samples. Although considerable quantitative differences in the measured reproductive indices between 2- and 3-year-old female channel catfish were observed, only GTH-Iβ mRNA levels appeared to be indicative of higher spawning rates.

University of Arkansas at Pine Bluff and USDA-ARS Stuttgart National Aquaculture Research Center. In the first year, testing of ultrasonagraphy as a method to evaluate pre-spawning white bass ovaries was commenced. In spring 2009, the first evaluation of ultrasound imaging of white bass ovaries was performed on 35 white bass held at the USDA ARS Stuttgart facilty. Fish were anesthetized and held upright, submerged in a holding tank. A Tela-Vet portable ultrasound system (Classic Medical, Tequesta, FL) equipped with a 5 to 8 Hz linear transducer was positioned anterior to the gonad, and moved posteriorly along the side of the fish. Three to five digital images of cross sections of the peritoneal cavity were captured along the length of the fish. Length, weight, and age of the fish were recorded. Following ultrasonography, each female white bass was injected with a 75 ng of slow-release GnRHa pellet. Females were held for 24 hours. Female response to hormone injection and the time to ovulation (if spawning occurred) was recorded.

The digital images of gonads are currently being examined. Depth, power, gain, frequency and decibel settings and the quality of each image collected by the of the ultrasound system are being summarized to optimize settings for ultrasonagraphy of white bass ovaries prior to testing to be performed in January and April 2010. We have hired a graduate research assistant to assist on this project. The student began his graduate education at the University of Arkansas at Pine Bluff in fall 2009.

Texas A&M University-Corpus Christi. Blood serum samples from female catfish dosed with vitamin C were received from Dr. Rex Dunham, Auburn University. Sample analyses are underway using HPLC/MS methodology. Optimization of a HPLC-MS method required 5 months of effort. Currently, the method can detect 18 steroids per analysis run. The only steroid of reproductive significance that exhibits minimal absorbance is estrogen. We will use MS methods for detection of this compound.

Objective 1b. *Improve conditioning and preparation of broodfish.*

University of Tennessee. All materials were purchased for the completion of a 11,780-L outdoor holding system. The outdoor holding system was assembled and has been in operation since July of 2009. All materials necessary for modification of the photoperiod controls for the indoor temperature controlled recirculation systems have been obtained and installation has began for the new photoperiod controls. Currently, the temperature and old photoperiod controls (non-independent system controls) are being used to maintain broodfish under natural outdoor photoperiod and temperature using sunrise/sunset tables and mean daily water temperatures of outdoor systems from the previous day.

A total of 108 Atlantic croaker *Micropogonias undulates* broodstock were collected with the help of researchers from Texas A&M University and the University of Arkansas at Pine Bluff (UAPB). Broodfish were collected from a power plant cooling water discharge in north Trinity Bay south of Baytown, Texas. The mean (± SD) size of the broodfish at time of capture was 29.4 ± 5.7 cm and 324.4 ± 93.0 g. The largest broodfish was 36.0 cm and 521.0 g, while the smallest broodfish was 24.4 cm and 190.1 g. All broodfish acquired were larger than the 14.0 to 18.0 cm size that is reported as the size of first maturation for Atlantic croaker in literature.

Scales were taken from nine random broodfish in an attempt to determine an approximate age structure of the broodfish population. Aging fish using seasonal scale growth rings is difficult for fish from the relatively temperature stable Gulf of Mexico. However, all of the broodfish in the sub-sample appeared to be between two and five years of age at the time of capture. Atlantic croakers mature within one year of age in the Gulf of Mexico. All of the broodfish collected for the completion of this research project are considered to be sexually mature based upon size and age and the majority of individuals had the opportunity to spawn at least once in the wild prior to capture.

Broodfish were transported from Trinity Bay to UAPB to be pellet trained. The fish were trained using methods refined by UAPB using a diet that was custom formulated by UAPB with consultation from Texas A&M. The diet was formulated based upon dietary trial literature for juvenile Atlantic croakers and marine broodfish nutrition literature from other species. Feed training has been completed and all surviving broodfish are actively consuming pellets at a rate of 4.6 to 10.0% of body weight per feeding when fed once every other day.

Prior to being allowed onto the UAPB research station, a subsample of the wild broodfish was subjected to a health inspection at the UAPB fish diagnostic disease center. The fish were deemed healthy, with only minor infestations of trematodes occurring in some of the individuals. As the trematodes require another host organism (typically a bird) to complete their life cycle and the croakers were to be held in quarantined recirculation systems, the trematodes were not considered to pose a serious health problem to the croakers or other fish on the research station.

Sixty-five of the 108 broodstock collected survived through the pellet-training phase producing a 60.2% survival rate. No mortalities have occurred after the completion of pellet training (> 30 days). The majority of mortalities appeared to be caused by stress induced by capture (hooking and handling complications), transport, temperature, and pellet training. The majority of mortalities (86.0%) occurred during initial feeding or during the pellet-training phase. Surviving broodstock were 43.1% (28) males and 56.9% (37) females.

Broodfish were transported and stocked for the initial photoperiod and temperature conditioning study on 9/18/09. Three female (mean ± SD; 333.2 ± 86.3 g, 28.7 ± 2.5 cm) and two male (327 ± 89.1 g, 28.0 ± 2.4 cm) Atlantic croaker broodfish were stocked into each of twelve 2,200-L tanks in three separate temperature control systems. The fish are currently being subjected to natural outdoor photoperiod and temperature regimes using sunrise/sunset tables and mean daily water temperatures of outdoor-systems from the previous day. The salinity of the recirculation systems is being maintained between 15 and 18 g/L. The fish are being offered 12% of body weight every other day with most tanks consuming up to 10% of body weight during each feeding. No spawning results have been obtained yet as the fish are fall spawners and are just beginning their spawning cycle. Normal spawning season ranges from October to March with peak spawning occurring in November in the Gulf of Mexico. Initial experiments have begun and the first statistical analysis of spawning results should be available during the spring of 2010.

University of Arkansas at Pine Bluff. All materials have been purchased for modification of the existing indoor and outdoor recirculating research systems and system construction has been completed (Figure 2). Fish are currently being held in the indoor system and are being conditioned for spawning for the broodstock lipid diet experiments scheduled for year 2 (Fall of 2010). The broodfish are currently being held in 15 to 18 g/L salinity. The fish were captured from water containing 24 to 28 g/L salinity at the power plant's water discharge in Trinity Bay, TX, and were originally held in tanks containing 30 to 32 g/L salinity. Initial mortality rates (first 21 d) were decreased when the salinity in the holding tanks was reduced to 15 to 18 g/L. Mortality rates increased again when the salinity was increased above 20 g/L. The Atlantic croaker broodstock also consume more feed and appear more active at salinities between 15 and 18 g/L. The fish become lethargic and reduce feed consumption when the salinity is increased above 20 g/L.

Figure 2. Indoor and outdoor recirculation systems were constructed to conduct studies on conditioning and spawning of Atlantic croaker.

All current diet literature was produced from studies using juvenile croakers, and diets that produce the best growth of juvenile croakers contain high protein concentrations (40-45%) and low to moderate lipid (5-8%) concentrations. As with many other marine species, including sciaenids, lipid would become more important to the brood prior to spawning than to the fingerlings, so higher lipid concentrations would be necessary. Following these general guidelines, a 48% protein, 18% lipid diet was formulated at UAPB with consultation from researchers at Texas A&M University. The diet was contracted to Burris Feeds (Cargill Inc.) for production and was extruded as 4.75-mm floating pellets. This diet will be used for pellet training of wild-captured brood croakers and will be fed to all croaker broodfish for the completion of year one objectives at UAPB and the University of Tennessee.

The broodfish were pellet trained using a diet formulated for Atlantic croaker broodstock based upon existing literature. Several attempts were made to feed train the fish. The broodfish were initially fasted for seven days prior to offering small portions of cut fish and shrimp with pellets mixed in. This practice was continued for several days while gradually replacing larger quantities of the fish and shrimp with pellets. This technique was largely unsuccessful as the fish tended to ignore the pellets and only eat the fish and shrimp. The fish would stop eating when fish and shrimp were removed from the diet offering.

The second method was to feed shrimp one day, fast for one day, feed pellets for one day, fast for one day, feed shrimp one day, in a repeating pattern. The fasting periods combined with only being offered food that they readily ate every four days was more successful at training the croakers to eat pellets. This method was still only marginally successful as many fish would simply fast for four days until they were offered shrimp. Many fish were attracted to the smell of the pellets, would suck them into their mouths, and hold them for extended periods (30 seconds or more), but they would eventually expel the pellets.

The third method was to fast the fish for seven days prior to offering pellets as the only food source. If the fish did not consume pellets after the initial feeding, they were offered pellets every other day until some individuals in the tank began to feed. After some of the fish began to feed, the other fish would quickly catch on as a learned behavior and start to feed on the pellets. Fish could be taken from tanks that were eating pellets and placed into tanks that were not yet consuming pellets. The fish in the tank would begin eating pellets within two days after watching the transplanted fish consume the pellets. This was the most successful method for pellet-training the fish and all fish were pellet trained within two weeks when using this method. As such, feed training has been completed for this year's broodstock and the fish are being offered 12% of body weight every other day. The fish are consuming pellets at a rate of up to 10.0% of body weight every other day.

Texas A&M University. Researchers from Texas A&M University have assisted in the collection and transport of brood Atlantic croaker from the Gulf of Mexico for use in the completion of UAPB's and the University of Tennessee's research objectives. Texas A&M University researchers have also assisted with the formulation of the initial broodstock diet that is being used by the University of Tennessee and UAPB in the initial photoperiod and temperature conditioning studies. All necessary reagents to perform proximate, fatty acid, and amino acid analyses have been purchased. Currently, we are awaiting egg and tissue samples from the initial spawning trials at the University of Tennessee and UAPB for biochemical analyses. These analyses will be used for statistical interpretation of year one results as well as to formulate experimental diets for years two and three.

Auburn University. In previous research we demonstrated the addition of highly unsaturated fatty acid sources [menhaden fish oil (MFO) enhanced with docosahexaenoic acid (DHA) and arachidonic acid (ARA) sources] significantly improved fry output of channel catfish females when mated to blue catfish males artificially. Additionally, preliminary information regarding mega-doses of vitamin C also suggested improved hybrid fry output. The question of whether vitamin C coupled with select lipid sources could further improve fry output remains to be determined. To evaluate these dietary manipulations, this year's research compared five diets (reference diets, vitamin C-enhanced diet, menhaden oil-enhanced diet, menhaden oil with DHA and ArA supplements, and a diet containing all of these ingredients) to determine which diet gives the highest fry output. The treatments were as follows: reference diet (RD) with 36% protein, 6% lipid and 100 ppm active C using Stay-C: RD with 1000 ppm active C (RD + C); RD with 2% added menhaden fish oil (RD-FO); RD with 1.5% MFO with 0.5% of high DHA and ARA meals (RD + HUFA); reference diet with 1.5% MFO with 0.5% of high DHA and ArA meals with 1000ppm active C (RD-ALL). The test diets were offered to the brood stock starting in the spring until they were harvested for spawning. To evaluate spawning success, egg production (number of eggs/g of egg mass (egg size), and number of eggs/g of female body weight (fecundity), and fertilization rate determined at 48 hours after fertilization.

In February, a total of 300, 5-year-old E-strain channel catfish were stocked in 15 ponds, 0.04 ha in size, with a mean weight of 3.30 kg per fish at a rate of 20 fish per pond. A random sample of 30 fish were measured and weighed and the condition index determined (666 cm, 3.30 kg, and 104.23%, respectively). Four spawning periods or runs were utilized for this research. For the first three, one pond of fish from each treatment was selected. Each pond was partially drained and 16 viable females removed based on external characteristics (abdominal fullness, softness and palpability of the ovaries, redness or swollen appearance of the genitals). Once all ponds had been partially harvested, a fourth spawning period was initiated for which all ponds were drain harvested and any remaining gravid females selected for spawning. Females selected for induced spawning were transferred to holding tanks supplied with continuous flow-through water, and placed individually in soft mesh bags. Total length, body weight, and grade were recorded. GMP grade luteinizing hormone-releasing hormone analogue (LHRHa) from American Peptide (Vista, CA) was utilized to induce ovulation. Hormone injections were administered intraperitoneally with a priming dose of 20 μg/kg followed by a resolving dose of 90 μg/kg.

Beginning 24 hours after injection, females were monitored for ovulation. Females releasing eggs were stripped and eggs were collected. Females not expressing eggs were examined every two to four hours for ovulation. Attempts to strip gametes ceased when no females remained that had swollen abdomens in response to the hormone treatment, and when all females had been anesthetized once to check for ovulation. For each spawn, eggs were batch weighed and a sub-sample collected to later determine number of eggs/g of egg mass, number of eggs/g of female body weight and total number of eggs for each female. Two samples of eggs were obtained from the first set of eggs during the stripping of each female. One of the samples was placed in the freezer (-80^{o}C) for later biochemical analysis, and the other sample was preserved using formalin (5% v/v). The latter was used to determine the egg weight. Egg weight was determined from total number of eggs in known weights of samples. After stripping of the eggs, the eggs and blue catfish sperm were gently swirled together, allowed to sit for two to ten minutes until they formed a mass, then the egg masses were placed in a water hardening trough with continuous, flowing, aerated reservoir water for 15 minutes. Finally, they were transferred to an egg basket in a hatching trough and held until hatch. The troughs had an air supply and a paddle wheel which was turned on when the youngest egg mass in the trough was at least 3 hours old. After 24 hours, the eggs received three treatments per day alternating 100 mg/l formalin followed by two treatments of 35 mg/l copper sulfate. The egg masses were evaluated 48 hours after addition of sperm to determine the percentage of developing eggs (fertilization rate).

Presently, only preliminary evaluations of the data are available. In addition to the data being preliminary, we have yet to obtain the batch sheets from the feed mill to confirm the diet order and proper addition of the ingredients. A composite sample from multiple bags was collected and analyzed for proximate composition and fatty acid composition to confirm lipid levels. This data is presented in Tables 1 and 2, respectively. It is clear from the analyses that Diet 2 is the menhaden fish oil supplement and that Diet 4 is the oil with high DHA and ArA meals added. Diet 5 should be the composite diet with all the additions; however, based on fatty acid profiles the lipid supplements were clearly not added to this diet. Hence, prior to making firm conclusions, the dietary treatments must be confirmed. Regardless of the dietary treatments, spawning data is exceptionally variable with age, length, strain as well as spawning period (or hatchery run) all having profound impacts on variation of the data. For this research a single strain and age of fish was utilized. This is intended to reduce variability of the data set for these variables. However, four spawning periods were also utilized, each producing different result presumably due to hatchery conditions. To further complicate spawning data, non-spawning events are often not included in the data analyses as they are not normally distributed.

Overall, the production of female brood stock was quite successful. Fish were obtained in the fall, stocked into the ponds with limited variation in size or age. The condition factor was good (104.2) indicating the fish were in good health prior to the initiation of the experiment. After feeding the diets over the course of the spring feeding period the fish were harvested and strip-spawned. The spawning success ranged from 70.8 to 80.1% of the total fish that were harvested or 82.3 to 87.5% of the fish were injected and 79.8 to 90.9% of the injected fish were successfully strip spawned (Table 3). This result is similar to those of other studies at this facility using similar techniques.

Egg production and estimated fry are presented in Table 4. The results from this year's production are similar to previous year with total number of eggs per kg of spawning fish ranging from 6356.9 to 7495.8. These results are typical for strip-spawning channel catfish. Spawning data is quite unique in that the data is not normally distributed and quite variable. For instance, we observed very poor survival in nursery run 2. If this data is excluded, there is a considerable increase in fry production per kg of fish (2125.9, 1696.2, 2543.8, 1443.4, 2003.9 for diets 1-5, respectively) these values are around 30% higher that values including all hatchery runs. It is this type of variation that makes statistical analyses of spawning data quite problematic. Overall, there do not seem to be any major trends in the data in terms of positive responses to the presented dietary treatment. This is consistent with previous observations in which catfish going into the fall with good condition indices tend not to respond to brood stock diet manipulations or their response is considerably muted. Whereas, in studies in which the condition factors were poor, there seemed to be very strong responses to dietary manipulations.

Presently, we are completing our analysis of the spawning data. Once the data has been finalized we will continue to evaluate alternative statistic analyses such as nested ANOVA and zero-inflated negative binomial regression (ZINB). Due to inherent variability in spawning data it is critical that alternative models be evaluated to provided the best insight into the response.

University of Florida. We have secured and stocked brood red-tailed sharks (*Epalzeorhynchos*

Table 1. Proximate analyses of test diets.

Diet	Moisture	Protein	Fat by acid hydrolysis	Fiber	Ash
Diet 1. Reference (RD)	9.21	35.3	7.36	3.57	5.50
Diet 2. RD + fish oil (RD+FO)	8.76	35.5	9.69	3.44	5.36
Diet 3. RD + 1000 ppt C (RD+C)	11.05	36.5	7.94	2.89	5.58
Diet 4. RD + FO+ DHA + ArA	8.58	35.1	12.47	3.22	5.31
Diet 5. RD + ALL	10.89	36.4	8.11	3.42	5.62

Table 2. Fatty acid profile of the test diets.

		Diet 1		Diet 2		Diet 3		Diet 4		Diet 5	
		Relative Basis%	Sample Basis%	Relative Basis%	Sample Basis%	Relative Basis%	Sample Basis%	Relative Basis%	Sample Basis%	Relative Basis%	Sample Basis%
Lauric	12:0	0.08	0.002	0.07	0.004	0.04	0.002	0.07	0.005	0.06	0.002
Myristic	14:0	2.65	0.070	3.34	0.161	2.75	0.094	3.45	0.253	2.75	0.091
Myristoleic	14:1	0.20	0.005	0.20	0.010	0.24	0.008	0.23	0.017	0.14	0.005
Pentadecanoic	15:0	0.26	0.007	0.34	0.016	0.26	0.009	0.35	0.026	0.29	0.010
Palmitic	16:0	20.14	0.533	23.14	1.117	21.09	0.718	23.49	1.722	21.93	0.726
Palmitoleic	16:1	4.99	0.132	6.33	0.306	5.21	0.177	6.56	0.481	5.42	0.180
Hexadecadienoic	16:2	0.21	0.006	0.26	0.013	0.17	0.006	0.26	0.019	0.18	0.006
Hexadecatrienoic	16:3	0.21	0.006	0.20	0.010	0.15	0.005	0.28	0.020	0.15	0.005
Hexadecatetraenoic	16:4	0.12	0.003	0.11	0.005	0.00	0.000	0.13	0.010	0.00	0.000
Heptadecanoic	17:0	0.38	0.010	0.41	0.020	0.27	0.009	0.44	0.032	0.30	0.010
Stearic	18:0	4.36	0.115	5.13	0.248	4.65	0.158	5.24	0.384	4.89	0.162
Oleic	18:1ω9	23.38	0.619	25.75	1.243	25.23	0.859	25.98	1.905	25.39	0.841
Oleic	18:1ω7	1.92	0.051	2.11	0.102	1.94	0.066	2.17	0.159	2.03	0.067
Linoleic	18:2ω6	27.36	0.724	21.84	1.054	27.62	0.940	20.02	1.467	26.97	0.893
Linolenic	18:3ω3	2.61	0.069	2.27	0.110	2.64	0.090	2.11	0.155	2.67	0.088
Octadecatetraenoic	18:4ω3	0.51	0.013	0.60	0.029	0.48	0.017	0.61	0.045	0.48	0.016
Arachidic	20:0	0.26	0.007	0.17	0.008	0.16	0.006	0.18	0.013	0.19	0.006
Eicosanoic	20:1ω11	0.17	0.004	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Eicosanoic	20:1ω9	1.51	0.040	0.47	0.023	0.86	0.029	0.47	0.035	0.57	0.019
Eicosadienoic	20:2ω6	0.08	0.002	0.00	0.000	0.00	0.000	0.07	0.005	0.00	0.000
Eicosatrienoic	20:3ω6	0.00	0.000	0.00	0.000	0.00	0.000	0.09	0.006	0.00	0.000
Arachidonic	20:4ω6	0.39	0.010	0.41	0.020	0.32	0.011	0.44	0.032	0.27	0.009
Arachidonic	20:4ω3	0.23	0.006	0.30	0.014	0.00	0.000	0.30	0.022	0.00	0.000
Eicosapentaenoic	20:5ω3	2.27	0.060	2.62	0.127	2.20	0.075	2.75	0.201	2.22	0.074
Erucic	22:1ω11	1.89	0.050	0.00	0.000	0.78	0.027	0.00	0.000	0.00	0.000
Docosapentaenoic	22:5ω3	0.44	0.012	0.46	0.022	0.31	0.011	0.52	0.038	0.33	0.011
Docosahexaenoic	22:6ω3	2.62	0.069	2.67	0.129	2.33	0.079	2.72	0.199	2.33	0.077
Other	n/a	0.76	0.020	0.76	0.037	0.29	0.010	1.07	0.078	0.44	0.015
		100.00	2.646	100.00	4.828	100.00	3.404	100.00	7.331	100.00	3.311
Total % ω3		8.69	0.230	8.93	0.431	7.96	0.271	9.01	0.661	8.02	0.266
Total % ω6		27.83	0.736	22.25	1.074	27.94	0.951	20.61	1.511	27.23	0.902

Table 3.Summary of stocking data for female channel catfish utilized in the maturation experiment. The broodstock were 5 year old fish. Based on a random sample of 30 fish the initial average length was 666.0 mm, average weight of 3.30 kg with a condition index of 104.2.

Diet	Initial weight (kg)	Harvest Weight (Kg)	Weight gain (kg)	Condition Index	Harvested Number	% Spawned
Diet 1.	3.34	3.79	0.45	126.7	19.0	75.5
Diet 2.	3.27	3.69	0.42	121.6	19.7	66.1
Diet 3.	3.26	3.50	0.24	119.9	19.0	70.5
Diet 4.	3.33	3.73	0.40	117.8	18.7	73.4
Diet 5.	3.29	3.63	0.34	116.7	17.0	80.1
PSE	0.7729	0.6122	0.8249	0.5940	0.4413	0.4814

Table 4. Summary of spawning results.

Diet	Harvest fish (Kg)	Spawning fish (Kg)	Total Egg (g)	Tot egg#	g egg/kg harvest	g egg/kg spawn	#egg/kg harvest	#egg/kg spawn	est fry#/kg spawn
1	71.9	53.8	7669.6	384830	106.6	142.5	5351.9	7144.4	1622.9
2	72.6	51.1	6856.3	326883	94.7	133.4	4517.6	6356.9	1204.1
3	66.3	49.1	7787.2	365723	117.8	158.7	5541.5	7459.3	1785.4
4	69.5	51.4	7176.0	358953	103.3	139.8	4915.1	6662.8	1443.4
5	61.4	49.0	7831.3	341570	128.0	163.3	5885.7	7495.8	1463.4
PSE	0.0377	0.8567	0.5935	0.5275	0.0585	0.1883	0.1882	0.3553	0.9758

Due to poor survival in nursery run 2, this data was excluded which results in the following data for estimated: fry no/kg fish were 2125.9, 1696.2, 2543.8, 1443.4, 2003.9 for diets 1-5, respectively with a P value of 0.712

bicolor) into nine tanks, 10 brood pairs per tank. The tanks are provided with flow through freshwater. We have secured and stocked brood mono sebae (*Monodactylus sebae*) into nine independent 2000-L tank systems, 30 fish per tank. These systems are equipped with biofilters which have been cycled to consume nitrogenous waste. We have constructed a floating egg collector for each tank. Salinity of culture water for the mono sebae is being increased 1.5 g/L per week until we reach 35 g/L; this is done slowly to acclimatize the fish to spawning conditions and to prevent loss of the bacteria in the biofilter.

We have worked with Rick Barrows, USDA-ARS, to formulate and make three test diets with varying levels of lipids and highly unsaturated fatty acids. Our original proposed formulations used linseed and squid oil to alter the levels of various fatty acids in the diets. We had to modify these formulations because linseed oil is not a practical dietary ingredient because of availability and the tendency for the oil to go rancid; squid oil is not practical because it also tends to go rancid rapidly. Therefore we have formulated three different diets with readily available dietary nutrients with long shelf lives. The three formulated diets include, an ornamental fish industry standard formulation containing 46% crude protein and 14% crude lipid (menhaden oil), a diet with 46% crude protein and 14% crude lipid using Algamac ARA to increase the highly unsaturated fatty acid levels, and a diet with 46% crude protein and 14% crude lipid using Algamac ARA and Algamac 3050 to increase the highly unsaturated fatty acids levels.

Populations of both red-tailed sharks and mono sebae are being fed the various experimental formulated diets. We expect to begin spawning these fish in the next six months and collecting the data to compare the effects of feeding these diets to brood fish on egg and larval quality (Figure 3).

Figure 3. 7-d-old *Monodactylus sebae* fry

Objective 1c. *Final identification of broodstock for spawning.*

USDA-ARS Catfish Genetics Research Unit. We have communicated with two commercial catfish farms about separating females into brood ponds based on ultrasound estimates of ovary size and then tracking reproductive success. However, we are currently waiting to see the results from the 2009 spawning data to determine if ultrasound has any predictive ability for spawning success of females. Our initial results suggest ultrasound is not accurate for predicting spawning success of females. If there is no ability to predict spawning success from ultrasound examination of ovary size, we will likely drop the commercial farm trials from the study given the labor and time required with no evidence indicating a successful outcome.

University of Arkansas at Pine Bluff and USDA-Stuttgart National Aquaculture Research Center. Concurrent with the ultrasonography of white bass females for pre-selection described above under Objective 1c, the digital images of gonads obtained by ultrasound will be analyzed for several morphometric measures (diameter, cross sectional area, perimeter length) to characterize the stage of gonadal maturation as the fish approach ovulation. This work is being undertaken presently.

Objective 2. *Improve spawning protocols to increase reproductive efficiency.*

Objective 2a. *Manage spawning conditions.*

University of Arkansas at Pine Bluff and USDA-ARS Stuttgart National Aquaculture Research Center. In year 1, a combination of 3- and 4-year-old white bass were held in environmental chambers and subjected to a 12-month photothermal regime. During the 12-month period, fish were fed a 45% protein diet twice daily to satiation. At the end of the 12-month cycle, fish were induced to spawn with hormone injections. Weights and lengths of females were determined prior to hormone injection. Fish were injected with a 75 ng slow release GnRHa pellet.

Ripe white bass females were strip-spawned into individual plastic containers. Milt from one male and a small amount of water were added to the each of the containers. A 10-mL sample of eggs from each female was placed into individual vials and frozen at -80°C. Eggs remaining in the containers were placed in individual McDonald hatching jars and treated with an iodine solution to disinfect the eggs, and a 150 mg/L solution of tannic acid to reduce adhesion and minimize clumping. After treating with tannic acid for 10 min, the eggs were rinsed with well water.

After 3 hours of water hardening, a sample of eggs from each female was removed from the McDonald hatching jar and placed into a glass Petri dish. Individual eggs were examined with a dissecting stereomicroscope to determine fertilization rates. Fertilized eggs were placed individually into 6-ml vials filled with well water. The eggs were incubated at approximately 18°C. The remaining eggs were maintained in the McDonald hatching jars and incubated at 18° C. Eggs in vials and McDonald hatching jars were examined every 6 hours. After approximately 19 hours of development, all the eggs ceased development. We have traced the cause of the failed hatch to a jar of tannic acid, which was more than one year old. It appears that old tannic acid can cause considerable losses at the egg stage. Personnel are in place, the broodstock are being phase shifted, and the protocols we set up appear to be giving us the results we anticipated. Accomplishment of our objectives should not be adversely affected by the problems encountered this spring.

USDA-ARS Catfish Genetics Research Unit. Two experiments were performed. Experiment one was done by randomly dividing groups of yearling USDA 403 fingerlings into two groups. Group one was fed to satiation and group two was fed one-half of that fed to group one. Both groups were exposed to a compressed annual temperature cycle of four months at 26°C and two months at 13°C. Exposure to three complete temperature cycles was done over two calendar years. Thirty females and 20 males from each group were stocked separately into two, 0.04-ha ponds with spawning containers in April. Male fish fed to satiation weighed 1004 g and females weighed 780 g. Male fish fed to one-half satiation weighed 754 g and females weighed 578 g. Spawning cans were checked regularly through the summer, however, there were no spawns produced from either of the groups.

Experiment two was designed to determine if fish exposed to extreme compressed cycles could be induced to spawn when they were one year old. One group of fish was USDA 103 and the other group was created from an industry pool. Both groups of fish were grown for 4 months at 26°C then exposed to cold conditions at 13°C for 1 month. A temperature cycle of 2 months at 26°C followed by 1 month of cold temperature was repeated until the fish had been exposed to three cycles of cold temperature and three cycles of warm temperature. The fish were then stocked into 0.04-ha spawning ponds with spawning cans and the cans checked regularly through the summer. No spawns occurred in either group.

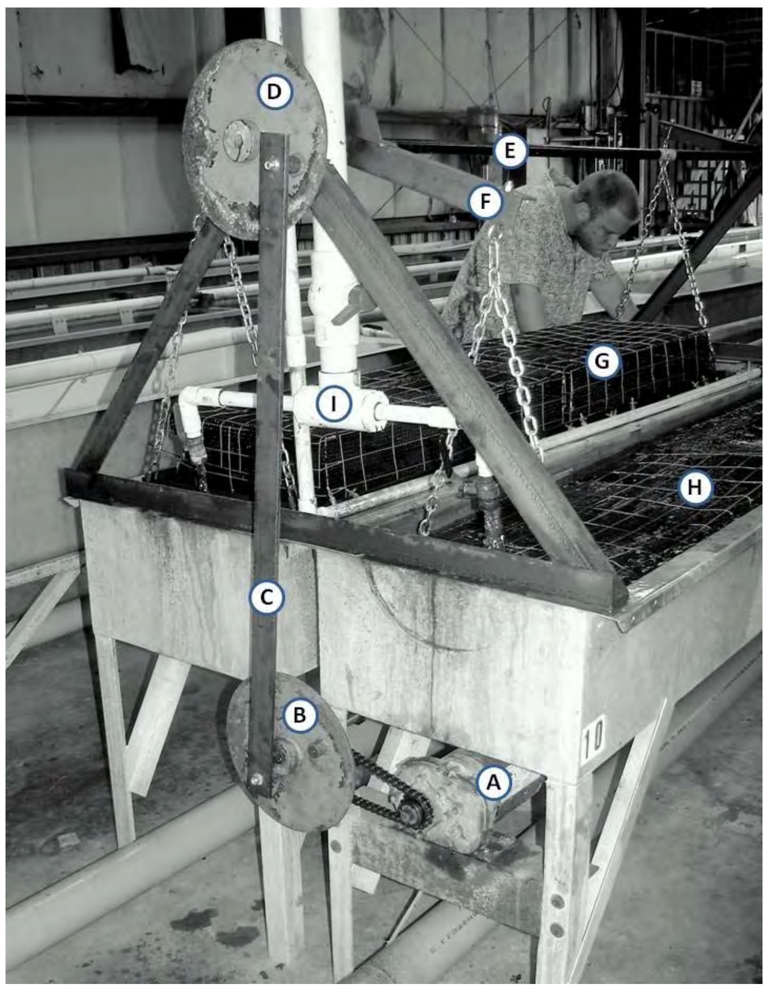
University of Tennessee. Although funding for this objective was not requested until year 2, significant work has been done to complete the goals of this objective. Reconfiguration of the outdoor recirculation spawning and holding systems was completed in July of 2009 and Atlantic croaker broodstock were temporarily held in the systems in August of 2009. New heating units that will be used to limit daily temperature fluctuations in the tanks have recently been delivered and are awaiting installation. The outdoor egg hatching tanks have been assembled and ready for egg incubation.

Broodfish have been collected and pellet trained although additional broodstock will be collected for completion of year 2 objectives. The ralgun implanter and the Ovaplant hormone pellets have been purchased and preliminary testing will occur this fall using extra broodstock.

Objective 2b. *Improving the Collection and Handling of Eggs*

USDA-ARS-Catfish Genetics Research Unit. A prototype catfish egg incubation system had been designed in collaboration with two commercial hatchery managers (Figure 4). The new incubator utilizes an angle-aluminum frame nearly the size of existing hatchery troughs. Three smaller baskets, which hold the spawns, are placed on the frame. The rotating paddles are eliminated, thus making more trough space available for eggs. Agitation and aeration is accomplished by lowering and raising the entire rack in and out of water maintained at oxygen saturation. Preliminary trials indicate that the new incubator moves water (and oxygen) through the egg masses more efficiently, preventing the suffocation and death of eggs in the center of the spawns when loaded at high densities. Part of the metabolic oxygen demand will be met with atmospheric oxygen, transferred into the egg masses while out of the water; liquid oxygen will be used if necessary to maintain the water near-saturation throughout the incubation period. This new design should allow farmers to incubate and hatch more eggs per trough while potentially decreasing water flow. If the theory behind the proposed technology proves sound, the new hatchery will be immediately available and applicable to commercial channel catfish hatcheries, as it is being tested under commercial conditions.

Figure 4. A vertical-lift incubator (the "See-Saw ") designed for channel catfish egg masses. (From Torrans et al. 2009; North American Journal of Aquaculture 71(4):354-359).



A prototype of the new incubator, named "the See-Saw" by collaborating farmers, was tested in two commercial channel catfish hatcheries during the 2007 and 2008 spawning seasons. The first trial determined the appropriate cycle interval (time to raise and lower the entire basket out of and back into the water) to be approximately ten seconds (6 cycles per minute). The second trial (modified with the appropriate cycle time) was tested with twice the egg density as is recommended. Although a thorough replicated comparison with standard incubators was not conducted, it operated flawlessly, leading us to this proposed large-scale study.

A Non-Funded Cooperative Agreement (NFCA) was established with Need More Fisheries LLC, Glen Allen, Mississippi to partner in this project. An NFCA is still in effect with Baxter Land Company, Inc., Watson, Arkansas, but the farm was decreasing channel catfish fingerling production this year and we felt that they would not produce enough eggs to conduct our research at their facility. They do remain as an alternative site.

During Year 1 of this project (2009 spawning season), sixteen standard hatchery troughs (eight side-by-side pairs) were equipped with the See-Saw incubation system. Due to the late approval of the project, most of this first season was used to design the system, purchase motors and material for fabrication of the supports, racks, and hatching baskets, and preliminary stress-testing of the system without live eggs.

Preliminary testing with live eggs determined that the vertical stroke was too great, resulting in an egg velocity through the water that resulted in partial disintegration of the spawns. The vertical stroke was reduced and that problem was solved.

Near the end of the spawning season the first comparative trial was conducted. Egg masses entering the hatchery were weighed and sampled to determine egg numbers. Pairs of troughs (one control and one test) were sequentially loaded with eggs. See-Saw and control troughs (n=4 of each) were loaded with 25.6 ± 0.5 egg masses per trough (474,947 ± 3002 and 472,878 ± 3892 eggs per trough, respectively). This is 2.0 - 1.5x higher than recommended loading rates. Water quality (water flow, dissolved oxygen, pH, total ammonia-nitrogen, and nitrite-nitrogen) were measured in the water supply and in each trough daily.

Results at a glance...

- *A novel catfish egg incubator has been designed and tested on two commercial farms. More eggs can be incubated using less water exchange than with conventional incubators, while achieving increased survival to swim-out stage.*

When the eggs hatched, sac fry were measured volumetrically and sub-sampled to determine total number, then transferred to rearing troughs. When the fry reached swim-up stage, they were measured volumetrically and sub-sampled to determine total number before transfer to rearing ponds (Figure 5). Our intent was to determine both hatch rate (live sac fry recovered as a percentage of eggs initially stocked) and survival to swim-up. However, when the sac fry were transferred, a significant portion of those from the control troughs were dead. We presume that they died prior to hatching from anoxia in the interior of the spawns and the egg shells later ruptured. Since we were not able to easily separate living from dead sac fry, we were not able to determine hatch rate, although we do presume that it was higher in the See-Saw. We plan to utilize a micro-fluorescent oxygen sensor in Year 2 so actual DO concentrations in the egg mass interiors can be determined under a variety of egg loading rates and ambient DO concentrations. We also noted that eggs in the See-Saw took approximately one additional day to hatch. It has been previously shown that eggs subjected to low oxygen stress will hatch prematurely and with a poorer hatch rate so this was not unexpected.

Survival to swim-up stage was significantly higher in the See-Saw than the traditional control troughs. Survival to swim-up stage averaged 53.6 ± 7.1% in the See-Saw, versus 23.3 ± 6.5 % for the control troughs, a 2.3-fold difference. While survival in the See-Saw was lower than expected, that was attributed to the generally poor egg quality from eggs collected at the end of the season (June 17-20). This project will continue through the 2010 and 2011 spawning seasons.

Figure 5. Comparison of eggs loaded to fry harvested between "See-Saw system and traditional control troughs

IMPACTS

Two commercial hatcheries are currently using the new incubator as a part of the on-farm trials. Further technology transfer will follow as the new system is more thoroughly tested.

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED

Manuscripts

Davis, K. B. 2009. Age at puberty of channel catfish, *Ictalurus punctatus*, controlled by thermoperiod. Aquaculture 292:244-247.

Torrans, L., B. Ott, R. Jones, B. Jones, J. Baxter, B. McCollum, A. Wargo III, and J. Donley. 2009. A vertical-lift incubator (the "Seesaw") designed for channel catfish egg masses. North American Journal of Aquaculture 71:354-359.

Presentations

Bosworth, B., G. Waldbieser, S. Quiniou, B. Small, and K. B. Davis. 2009. Factors affecting spawning success in channel catfish. Catfish Farmers of American Research Symposium, Natchez, Mississippi, 5-7 March 2009.

Torrans, L., B. Ott, R. Jones, B. Jones, J. Baxter, B. McCollum, A. Wargo III, and J. Donley. 2009. The "See-Saw"–a high-intensity catfish egg incubator designed to save space and conserve water. Catfish Farmers of America Catfish Research Symposium, Natchez, Mississippi, 5-7 March 2009.

◆ ◆ ◆

SUPPORT OF CURRENT PROJECTS

Title	Yr	SRAC Funding	Other Support: University	Industry	Other Federal	Other	Total Other Support	Total SRAC+ Other Support
Publications, Videos and	1	50,000	43,950	-0-	-0-	-0-	43,950	93,950
Computer Software	2	60,948	30,737	-0-	-0-	-0-	30,737	91,685
	3	45,900	35,710	-0-	1,000	-0-	36,710	82,610
	4	60,500	41,000	-0-	-0-	-0-	41,000	101,500
	5	67,000	47,000	-0-	-0-	-0-	47,000	114,000
	6	77,358	52,975	-0-	-0-	-0-	52,975	130,333
	7	82,205	43,000	-0-	-0-	-0-	43,000	125,205
	8	77,383	47,000	-0-	-0-	-0-	47,000	124,383
	9	60,466	47,000	-0-	-0-	-0-	47,000	107,466
	10	50,896	30,000	-0-	-0-	-0-	30,000	80,896
	11	45,723	30,000	-0-	-0-	-0-	30,000	75,723
	12	71,288	30,000	-0-	-0-	-0-	30,000	101,288
	13	80,106	30,000	-0-	-0-	-0-	30,000	110,106
	14	79,913	30,000	-0-	-0-	-0-	30,000	109,913
Total		**909,686**	**538,372**	**-0-**	**1,000**	**-0-**	**539,372**	**1,449,058**
Innovative Technologies and	1	314,409	193,931	-0-	-0-	-0-	193,931	508,340
Methodologies for Commercial-	2	267,316	217,676	-0-	-0-	-0-	217,676	484,992
Scale Pond Aquaculture	3	204,857	163,173	-0-	-0-	-0-	163,173	368,030
	4	149,144	106,405	-0-	-0-	-0-	106,405	255,549
Total		**935,726**	**681,185**	**-0-**	**-0-**	**-0-**	**681,185**	**1,108,571**
Feed Formulation and	1	102,913	39,363	-0-	-0-	-0-	39,363	142,276
Feeding Strategies for Bait	2	107,198	50,345	-0-	-0-	-0-	50,345	157,543
and Ornamental Fish	3	124,952	52,363	-0-	-0-	-0-	52,363	177,315
Total		**335,063**	**142,071**	**-0-**	**-0-**	**-0-**	**142,071**	**477,134**
Development and Evaualtion	1	157,818	75,241	-0-	-0-	-0-	75,241	233,059
of Pond Inventory Methods	2	137,423	72,420	-0-	-0-	-0-	72,420	209,843
Total		**295,241**	**147,661**	**-0-**	**-0-**	**-0-**	**147,661**	**442,902**
Economic Forecasting and	1	75,000	37,825	-0-	-0-	-0-	37,825	112,825
Policy Analysis Models for	2	75,000	38,163	-0-	-0-	-0-	38,163	113,163
Catfish and Trout								
Total		**150,000**	**75,988**	**-0-**	**-0-**	**-0-**	**75,988**	**225,988**
Improving Reproductive	1	222,633	53,970	-0-	-0-	-0-	53,970	276,603
Efficiency of Cultured Finfish	2	195,693	58,630	-0-	-0-	-0-	58,630	254,323
	3	78,456	38,166	-0-	-0-	-0-	38,166	116,622
Total		**496,782**	**150,766**	**-0-**	**-0-**	**-0-**	**150,766**	**647,548**

SRAC RESEARCH AND EXTENSION PROJECTS

Project	Duration	Funding	Grant No.
*Analysis of Regional and National Markets for Aquacultural Products Produced for Food in the Southern Region. Dr. J. G. Dillard, Mississippi State University, Principal Investigator	04/01/88-06/30/90		
	Project Total	**$346,038**	87-CRSR-2-3218
*Preparation of Southern Regional Aquaculture Publications. Dr. J. T. Davis, Texas A&M University, Principal Investigator	01/01/88-12/31/90		
	Project Total	**$150,000**	87-CRSR-2-3218
*Performance of Aeration Systems for Channel Catfish, Crawfish, and Rainbow Trout Production. Dr. C. E. Boyd, Auburn University, Principal Investigator	03/01/88-10/31/90		
	Project Total	**$124,990**	87-CRSR-2-3218
*Develop a Statistical Data Collection System for Farm-Raised Catfish and Other Aquaculture Products in the Southern Region. Dr. J. E. Waldrop, Mississippi State University, Principal Investigator	06/01/89-11/30/90		
	Project Total	**$13,771**	88-38500-4028
*Immunization of Channel Catfish. Dr. J. A. Plumb, Auburn University, Principal Investigator	Yr. 1-05/02/89-04/30/90	$50,000	88-38500-4028
	Yr. 2-05/01/90-04/30/91	49,789	89-38500-4516
	Project Total	**$99,789**	
*Enhancement of the Immune Response to *Edwardsiella ictaluri* in Channel Catfish. Dr. J. R. Tomasso, Clemson University, Principal Investigator	Yr. 1-05/02/89-04/30/90	$46,559	88-38500-4028
	Yr. 2-05/01/90-10/31/91	51,804	89-38500-4516
	Project Total	**$98,363**	
*Effect of Nutrition on Body Composition and Subsequent Storage Quality of Farm-Raised Channel Catfish. Dr. R. T. Lovell, Auburn University, Principal Investigator	Yr. 1-05/02/89-04/30/90	$274,651	88-38500-4028
	Yr. 2-05/01/90-04/30/91	274,720	89-38500-4516
	Yr. 3-05/01/91-12/31/92	273,472	90-38500-5099
	Project Total	**$822,843**	

*Project Completed

Project	Duration	Funding	Grant No.
*Harvesting, Loading and Grading Systems for Cultured Freshwater Finfishes and Crustaceans. Dr. R. P. Romaire, Louisiana State University, Principal Investigator	Yr. 1-05/02/89-04/30/90	$124,201	88-38500-4028
	Yr. 2-05/01/90-04/30/91	124,976	89-38500-4516
	Yr. 3-05/01/91-04/30/93	124,711	90-38500-5099
	Project Total	**$373,888**	
*Preparation of Extension Publications on Avian Predator Control in Aquaculture Facilities. Dr. James T. Davis, Texas A&M University, Principal Investigator	05/01/90-12/31/92		
	Project Total	**$15,000**	89-38500-4516
*National Extension Aquaculture Workshop. Dr. Carole Engle, University of Arkansas at Pine Bluff, Principal Investigator	10/01/91-09/30/92		
	Project Total	**$3,005**	89-38500-4516
*Educational Materials for Aquaculturists and Consumers. Dr. J. T. Davis, Texas A&M University, Principal Investigator	Yr. 1-05/01/91-04/30/92	$3,971	87-CRSR-2-3218
		35,671	88-38500-4028
	Total Yr. 1	$39,642	
	Yr. 2-06/01/92-05/31/93	$58,584	91-38500-5909
	Yr. 3-06/01/93-12/31/94	34,500	92-38500-7110
	Project Total	**$132,726**	
*Characterization of Finfish and Shellfish Aquacultural Effluents. Dr. J. V. Shireman, University of Florida, Principal Investigator	Yr. 1-05/01/91-04/30/92	$45,131	88-38500-4028
		65,552	89-38500-4516
		34,317	90-38500-5099
	Total Yr. 1	$145,000	
	Yr. 2-06/01/92-05/31/93	$168,105	91-38500-5909
	Yr. 3-06/01/93-12/31/94	$128,937	92-38500-7110
	Project Total	**$442,042**	
*Food Safety and Sanitation for Aquacultural Products: Microbial. Dr. J. L. Wilson, University of Tennessee, Principal Investigator	Yr. 1-04/01/92-03/30/93	$12,649	89-38500-4516
		71,608	90-38500-5099
	Total Yr. 1	$84,257	
	Yr. 2-06/01/93-05/31/94	$213,106	92-38500-7110
	Yr. 3-06/01/94-05/31/95	$237,975	93-38500-8393
	Project Total	**$535,338**	
*Project Completed			

Project	Duration	Funding	Grant No.
*Aquaculture Food Safety: Residues. Dr. George Lewis, University of Georgia, Principal Investigator	Yr. 1-09/11/92-09/30/93	$99,393	91-38500-5909
	Yr. 2-10/01/93-09/30/94	$44,631	90-38500-5099
		107,050	91-38500-5909
	Total Yr. 2	$151,681	
	Yr. 3-10/01/94-09/30/95	$89,463	93-38500-8393
	Yr. 4-10/01/95-09/30/96	$11,392	93-38500-8393
	Project Total	**$351,929**	
*National Coordination for Aquaculture Investigational New Animal Drug (INAD) Applications. (In cooperation with other Regional Aquaculture Centers and USDA)	Yr. 1-09/01/93-08/31/94		
	Project Total	**$2,000**	90-38500-5099
*Improving Production Efficiency of Warmwater Aquaculture Species Through Nutrition. Dr. Delbert Gatlin, Texas A&M University, Principal Investigator	Yr. 1-01/01/94-12/31/94	$28,148	90-38500-5099
		123,705	91-38500-5909
		128,444	92-38500-7110
	Total Yr. 1	$280,297	
	Yr. 2-01/01/95-12/31/95	$38,059	92-38500-7110
		175,450	93-38500-8393
		32,397	94-38500-0045
	Total Yr. 2	$245,906	
	Yr. 3-01/01/96-12/31/96	$23,907	93-38500-8393
		210,356	94-38500-0045
	Total Yr. 3	$234,263	
	Project Total	**$760,466**	
*Delineation and Evaluation of Catfish and Baitfish Pond Culture Practices. Dr. Michael Masser, Auburn University, Principal Investigator	Yr. 1-04/01/94-03/31/95	$75,530	92-38500-7110
		43,259	93-38500-8393
	Total Yr. 1	$118,789	
	Yr. 2-04/01/95-03/31/96	$113,406	94-38500-0045
	Yr. 3-04/01/96-03/31/97	$28,517	93-38500-8393
		72,281	94-38500-0045
	Total Yr. 3	$100,798	
	Project Total	**$332,993**	
*Project Completed			

Project	Duration	Funding	Grant No.
*Optimizing Nutrient Utilization and Waste Control through Diet Composition and Feeding Strategies. Dr. Kenneth Davis, University of Memphis, Principal Investigator	Yr. 1-12/01/96-11/30/97	$241,476	95-38500-1411
	Yr. 2-12/01/97-11/30/98	$47,105	95-38500-1411
		210,047	96-38500-2630
	Total Yr. 2	$257,152	
	Yr. 3-12/1/98-11/30/99	$34,365	96-38500-2630
		199,811	97-38500-4124
	Total Yr. 3	$234,176	
	Project Total	$732,804	
*Management of Environmentally-Derived Off-Flavors in Warmwater Fish Ponds. Dr. Tom Hill, University of Tennessee, Principal Investigator	Yr.1-06/01/96-05/31/97	$29,349	93-38500-8393
		34,918	94-38500-0045
		186,560	95-38500-1411
	Total Yr. 1	$250,827	
	Yr. 2-06/01/97-05/31/98	$68,718	94-38500-0045
		97,393	95-38500-1411
		84,031	96-38500-2630
	Total Yr. 2	$250,142	
	Yr. 3-06/1/98-05/31/99	$154,621	96-38500-2630
		74,645	97-38500-4124
	Total Yr. 3	$229,266	
	Yr. 4-06/01/99-05/31/00	$80,900	98-38500-5865
	Yr. 5-06/01/00-05/31/01	$55,146	99-38500-7375
	Project Total	**$866,281**	
*National Aquaculture Extension Conference (In cooperation with other Regional Aquaculture Centers)	01/01/97-12/31/97	$3,392	93-38500-8393
		308	95-38500-1411
	Project Total	**$3,700**	
*Verification of Recommended Management Practices for Major Aquatic Species. Dr. Carole Engle, University of Arkansas at Pine Bluff, Principal Investigator	Yr. 1-01/01/97-12/31/97	$31,410	95-38500-1411
	Yr. 2-01/01/98-12/31/98	$7,186	95-38500-1411
		58,928	96-38500-2630
	Total Yr. 2	$66,114	
	Yr. 3-01/01/99-12/31/00	$62,781	99-38500-4124
	Project Total	**$160,305**	

*Project Completed

Project	Duration	Funding	Grant No.
Publications, Videos and Computer Software. Dr. Michael Masser, Texas A&M University, Principal Investigator (Continuing project)	Yr. 1-04/01/95-03/31/96	$50,000	94-38500-0045
	Yr. 2-04/01/96-03/31/97	$13,405	93-38500-8393
		47,543	94-38500-0045
	Total Yr. 2	$60,948	
	Yr. 3-04/01/97-03/31/98	$45,900	96-38500-2630
	Yr. 4-04/01/98-03/31/99	$60,500	97-38500-4124
	Yr. 5-04/01/99-03/31/00	$67,000	98-38500-5865
	Yr. 6-07/01/00-06/30/01	$77,358	00-38500-8992
	Yr.7-07/01/01-06/30/02	$82,205	2001-38500-10307
	Yr.8-01/01/03-12/31/03	$77,383	2002-38500-11805
	Yr.9-04/01/04-03/31/05	$916	2002-38500-11805
		59,550	2003-38500-12997
	Total Yr. 9	$60,466	
	Yr. 10-03/01/05-02/28/06	$50,896	2004-38500-14387
	Yr. 11-03/01/06-02/28/07	$45,723	2005-38500-15815
	Yr. 12-03/01/07-02/29/08	$71,288	2006-38500-16977
	Yr. 13-05/01/08-04/30/09	$80,106	2007-38500-18470
	Yr. 14-05/01/09-04/30/10	$79,913	2008-38500-19251
	Project Total	**$909,686**	
*Control of Blue-green Algae in Aquaculture Ponds. Dr. Larry Wilson, University of Tennessee, Principal Investigator	Yr. 1-01/01/99-12/31/99	$25,147	96-38500-2630
		105,167	97-38500-4124
		177,260	98-38500-5865
	Total Yr. 1	$307,574	
	Yr. 2-01/01/00-12/31/00	$975	96-38500-2630
		17,394	97-38500-4124
		158,608	98-38500-5865
		98,993	99-38500-7375
	Total Yr. 2	$275,970	
	Yr. 3-01/01/01-12/31/01	$26,186	97-38500-4124
		7,202	98-38500-5865
		188,550	99-38500-7375
		24,277	00-38500-8992
	Total Yr. 3	$246,215	
	Project Total	**$829,759**	
*Management of Aquacultural Effluents from Ponds. Dr. John Hargreaves, Mississippi State University, Principal Investigator	Yr. 1-04/01/99-03/31/00	$100,000	97-38500-4124
		127,597	98-38500-5865
	Total Yr. 1	$227,597	
	Yr. 2-04/01/00-03/31/01	$221,146	99-38500-7375
	Yr. 3-04/01/01-03/31/02	$106,610	2000-38500-8992
	Project Total	**$555,353**	
*Project Completed			

Project	Duration	Funding	Grant No.
*Development of Improved Harvesting,	Yr. 1-01/01/01-12/31/01	$287,053	00-38500-8992
Grading and Transport Technology	Yr. 2-01/01/02-12/31/02	$14,259	98-38500-5865
for Finfish Aquaculture. Dr. Ed Robinson,		39,720	99-38500-5865
Mississippi State University, Principal		14,757	00-38500-8992
Investigator		189,955	01-38500-10307
	Total Yr. 2	$258,691	
	Yr. 3-01/01/03-12/31/03	$47,937	00-38500-8992
		139,390	01-38500-10307
	Total Yr. 3	$187,327	
	Project Total	**$733,071**	
*National Aquacultue Extension			
Conference-2007 (In cooperation with	11/01/05-10/31/06		
other Regional Aquaculture Centers)	**Project Total**	**$5,000**	2002-38500-11805
*Identification, Characterization, and	Yr. 1-03/01-03-02/28/04	$28,029	2000-38500-8992
Evaluation of Mechanisms of Control of		126,778	2001-38500-10307
Bolbophorus-like Trematodes and		67,298	2002-38500-11307
Flavobacterium columnaris-like Bacteria.	Total Yr. 1	$222,105	
Dr. John Hawke, Louisiana State University,	Yr. 2-03/01-04-02/28/2005	$27,126	2000-38500-8992
Principal Investigator		47,498	2001-38500-10307
		151,614	2002-38500-11805
		778	2003-38500-12997
	Total Yr. 2	$227,016	
	Yr. 3-03/01/05-02/28/06	$24,074	2001-38500-10307
		15,417	2002-38500-11805
		104,918	2003-38500-12997
	Total Yr. 3	$144,409	
	Project Total	**$593,530**	
*Improving Reproductive Efficiency to	Yr. 1-03/01/04-02/28/05	$1,000	2001-38500-10307
Produce Channel × Blue Hybrid Catfish Fry.		114,935	2002-38500-11805
Dr. Rex Dunham, Auburn University,	Total Yr. 1	$115,935	
Principal Investigator	Yr. 2 -03/01/05-02/28/06	$99,000	2003-38500-12997
	Yr. 3-03/01/06-02/28/07	$14,549	2002-38500-11805
		28	2003-38500-12997
		100,423	2004-38500-14387
	Total Yr. 3	$115,000	
	Yr. 4-03/01/07-02/29/08	$112,128	2005-38500-15815
	Project Total	**$442,063**	
*Project Completed			

Project	Duration	Funding	Grant No.
*Innovative Technologies and Methodologies for Commercial-Scale Pond Aquaculture. Dr. Claude Boyd, Auburn University, Principal Investigator	Yr.1-08/01/04-07/31/05	$1,053	2000-38500-8992
		167,433	2002-38500-11805
		145,923	2003-38500-12997
	Total Yr. 1	$314,409	
	Yr. 2-08/01/05-07/31/06	$39	2002-38500-11805
		116,043	2003-38500-12997
		151,234	2004-38500-14387
	Total Yr. 2	$267,316	
	Yr.3-08/01/06-07/31/07	$120	2002-38500-11805
		69,310	2003-38500-12997
		38,919	2004-38500-14387
		96,508	2005-38500-15815
	Total Yr. 3	$204,857	
	Yr.4-08/01/07-07/31/08	$62,491	2004-38500-14387
		51,892	2005-38500-15815
		34,760	2006-38500-16977
	Total Yr. 4	$149,144	
	Project Total	**$935,726**	
*Feed Formulation and Feeding Strategies for Bait and Ornamental Fish. Dr. Rebecca Lochmann, University of Arkansas at Pine Bluff, Principal Investigator	Yr. 1-05/01/05-04/30/06	$102,913	2003-38500-12997
	Yr. 2-05/01/06-04/30/07	$107,198	2004-38500-14387
	Yr. 3-05/01/07-04/30/08	$66,789	2004-38500-14387
		58,163	2005-38500-15815
	Total Yr. 3	$124,952	
	Project Total	**$335,063**	
Development and Evaluation of Pond Inventory Methods. Dr. David Heikes, University of Arkansas at Pine Bluff, Principal Investigator	Yr. 1-05/01/07-04/30/08	$1,648	2003-38500-12997
		18,463	2004-38500-14387
		137,707	2005-38500-15815
	Total Yr. 1	$157,818	
	Yr. 2-05/01/08-04/30/09	$12,917	2004-38500-14387
		124,505	2006-38500-16977
	Total Yr. 2	$137,423	
	Project Total	**$295,241**	
Economic Forecasting and Policy Analysis Models for Catfish and Trout. Dr. Carole Engle, University of Arkansas at Pine Bluff, Principal Investigator	Yr. 1-08/01/07-07/31/08	$75,000	2006-38500-16977
	Yr. 2-08/01/08-07/31/09	$42,502	2005-38500-15815
		32,498	2006-38500-16977
	Total Yr. 2	$75,000	
	Project Total	**$150,000**	

Project	Duration	Funding	Grant No.
Improving Reproductive Efficiency of Cultured Finfish. Dr. Brian Small, USDA/ARS, Principal Investigator	Yr. 1-02/01/09-01/31/10	$34,044	2005-38500-15815
		188,589	2006-38500-16977
		$222,633	
	Projected-Yr. 2	$195,693	
	Projected-Yr. 3	$78,456	
	Project Total	**$496,782**	

Southern Regional Aquaculture Center, P.O. Box 197, Stoneville, Mississippi 38776

Visit our web site at http://www.msstate.edu/dept/srac to obtain SRAC publications and other information.

Work summarized in this report was supported in part by Grant Nos. 2005-38500-15815, 2006-38500-16977, 2007-38500-18470 and 2008-38500-19251from the United States Department of Agriculture, National Institute of Food and Agriculture.