FEED THE FUTURE INNOVATION LAB FOR COLLABORATIVE RESEARCH ON AQUACULTURE AND FISHERIES (AQUAFISH INNOVATION LAB)

AQUAFISH INNOVATION LAB TWELFTH ANNUAL REPORT

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Oregon State University
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Oregon State University

AQUAFISH INNOVATION LAB

AQUAFISH INNOVATION LAB
TWELFTH ANNUAL REPORT

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Cover Photo
Farmers and researchers at a fish pond during a short-term training in Bangladesh. 2017. Credit: Shahroz Mahean Haque.

Photos
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MANAGEMENT ENTITY INFORMATION

The Management Entity (ME) for the AquaFish Innovation Lab is headquartered at Oregon State University (OSU) in Corvallis, Oregon.

AQUAFISH INNOVATION LAB MANAGEMENT OFFICE

Hillary Egna	Director and Lead Principal Investigator, AquaFish Innovation Lab
Ford Evans	Associate Director, AquaFish Innovation Lab
Jenna Borberg	Associate Director – Research, AquaFish Innovation Lab
Kathryn Goetting	Assistant Director – Compliance & Operations, AquaFish Innovation Lab

TECHNICAL AND ADVISORY COMMITTEE INFORMATION

The AquaFish Innovation Lab received advice in FY18 on emerging developments and technical issues through open dialogue with one internal and two external advisory groups: Emerging Issues Panel, Regional Centers of Excellence, and External Program Advisory Council.

REGIONAL CENTERS OF EXCELLENCE (RCE)

The RCEs provide technical advice on emerging issues and gaps in the portfolio from a regional perspective. Centers develop useful materials for Missions and other regional stakeholders and end-users, and gauge opportunities for collaboration based on regional and national needs. RCE Coordinators assist the Director in cases where a screening process is required in advance of an Initial Environmental Examination. The RCE Coordinators for FY18 were:

RCE – Africa: *Charles Ngugi (East Africa) & Steve Amisah (West Africa)*
RCE – Asia: *Yuan Derun (Southeast Asia) & Wilfred Jamandre (Southeast Asia)*
RCE – Latin America & Caribbean: *Wilfrido Contreras-Sanchez (Central America and the Caribbean) & Maria Célia Portella (South America)*

EXTERNAL PROGRAM ADVISORY COUNCIL (EPAC)

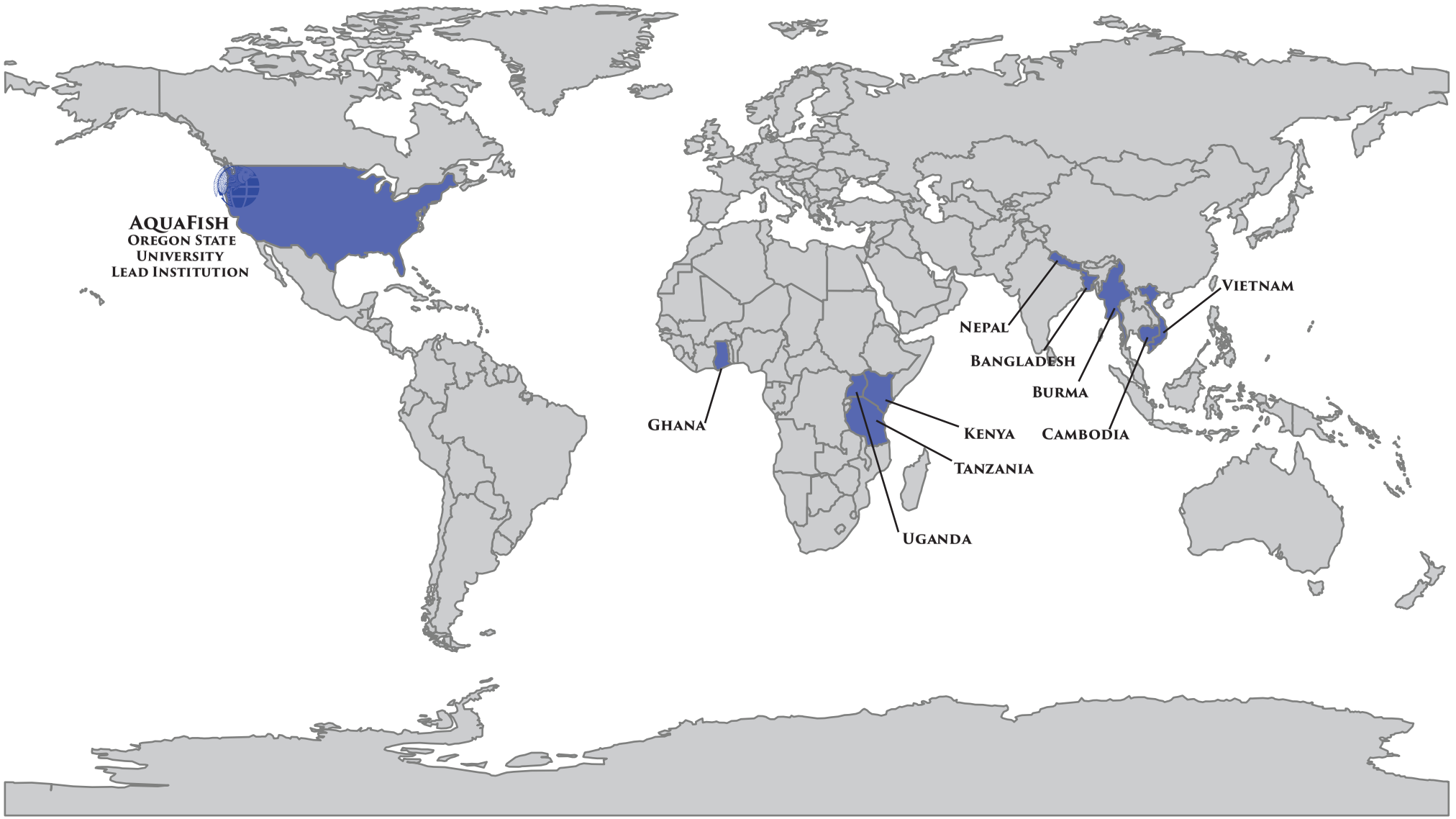
The EPAC provides advice on global program direction and annual critiques of research projects during annual or regional meetings to assist the Director in gauging project performance; participates in the programmatic review process for proposals on an as-needed basis, provided there are no conflicts of interest; and helps the Director network and link the AquaFish Innovation Lab with non-governmental organizations (e.g., CGIAR), and others. The EPAC members for FY18 included:

Africa: *Nancy Gitonga*
Asia: *Liping Liu*

EMERGING ISSUES PANEL (EIP)

The EIP was part of the original 2006 AquaFish CRSP proposal and was a non-voting, non-policy setting technical advisory panel that provided scientific advice from across the broad spectrum of aquaculture, fisheries, and water resources sectors to the Management Office. EIP members were Oregon State University faculty and other experts who volunteered their time to serve on the panel. EIP members did not engage in AquaFish CRSP/Innovation Lab activities and were not considered AquaFish CRSP/Innovation Lab staff. Safeguards were taken to eliminate conflicts of interest. The EIP was reinitiated in FY18 to assist with graceful exit planning and closedown at OSU.

AquaFish Research Project Countries FY18



PROGRAM PARTNERS

The AquaFish Innovation Lab partners and collaborates with institutions around the world to maximize the benefits of aquaculture and fisheries research, technology development, and capacity building. AquaFish IL US and Host Country (HC) participants accomplish this by sharing expertise, conducting collaborative research, engaging and educating stakeholders, and leveraging opportunities through a strong and growing aquaculture network.

Since inception in 2006, AquaFish has fostered linkages with approximately 300 institutions globally. The AquaFish Innovation Lab builds and maintains its network through formal funded partnerships as well as through non-funded collaborations.

Funded Project Partners in FY18

(The list below includes all institutions in formally-funded partnership with the AquaFish IL during FY18.)

Bangladesh
Bangladesh Agricultural University
Khulna University
Patuakhali Science and Technology University
Shushilan NGO

Burma
Yangon University

Cambodia
Inland Fisheries Research and Development Institute

Ghana
Farmerline
Kwame Nkrumah University of Science and Technology

Kenya
Kenyatta University
University of Eldoret

Nepal
Agriculture and Forestry University
Directorate of Fisheries Development
Nepal Agricultural Research Council

Tanzania
Institute of Marine Sciences, University of Dar es Salaam
Sokoine University of Agriculture
Western Indian Ocean Marine Science Association

Uganda
Makerere University
National Fisheries Resources Research Institute-Aquaculture Research and Development Center

US
Alabama A&M University
Auburn University
North Carolina State University
Oregon State University
Purdue University
Michigan State University
University of Arizona
University of Arkansas at Pine Bluff
University of Connecticut at Avery Point
University of Hawaii at Hilo
University of Michigan
University of Rhode Island
Virginia Polytechnic Institute and State University

Vietnam
Can Tho University

Current and Former AquaFish IL Linkages (FY06-FY18)

(This is a comprehensive list of AquaFish IL linkages from inception in 2006 through FY18.)

Argentina
Universidad Nacional del Comahue

Australia
Australian Center for International Agricultural Research
Monash University (Melbourne)
University of Tasmania

Bangladesh
Bangladesh Agricultural University
Bangladesh Department of Fisheries
CGIAR-WorldFish, South Asia & Bangladesh
Chanchal Hatchery (World Fish Supported)
Hajee Mohammad Danesh Science & Technology University
Institution of Nutrition and Food Science (University of Dhaka)
Khulna University
Patuakhali Science and Technology University
Shushilan NGO
University of Dhaka
WorldFish Aquaculture Income & Nutrition
WorldFish Farmer's Group

Brazil
Embrapa Meio Ambiente
Sao Paulo State University
Universidad Estadual Paulista, Centro de Acüicultura, Jaboticabal
Universidad Federal do Amazonas

Burma
Yangon University

Cambodia
Cambodia Department of Conservation
Cambodia HARVEST Project, USAID
Cambodia Molecular Genetic Group, Health Scientific Research Centre University Health Sciences
Department of Aquaculture Development
Department of Fisheries, Post-Harvest Technologies & Quality Control of Fisheries Administration
Fisheries Administration in Cambodia
Freshwater Aquaculture Research & Development Center
Hun Sen Aquaculture Institute
Inland Aquaculture Extension & Productivity Improvement Project
Inland Fisheries Research and Development Institute
Institution for Research in Food and Development
Kampong Cham National School of Agriculture
Kandal Fisheries Administration
Marine Aquaculture Research and Development Center
Mekong River Commission
Ministry of Agriculture, Forestry, and Fisheries
Phnom Penh Fisheries Administration
Prek Leap National School of Agriculture
Royal University of Agriculture
Royal University of Law and Economics
WorldFish Center, Cambodia

Canada
International Development Research Centre

Chile
Foundation Chile

China
China Aquatic Products Processing & Marketing Association
Guizhou Normal University
Hainan University
Haoshideng Shrimp Farm
Huazhong University
Huiting Reservoir Fisheries Management Company
Shanghai Ocean University
Sichuan Aquacultural Engineering Research Center
Southwest University
Tongwei Co. Ltd.
Wuhan University
Xiamen University
Zhanghe Reservoir Fisheries Management Company
Zhejiang University

Colombia
Centro Internacional de Agricultura Tropical

Costa Rica
University of Costa Rica

Ecuador
Ecostas

Egypt
Academy of Scientific Research & Egyptian Universities
Central Laboratory for Aquaculture Research
Egyptian Society of Agribusiness
Ministry of Agriculture & Land Reclamation

Ethiopia
Ethiopian Institute of Agricultural Research

Ghana
FAO-Ghana (not FAO Regional Office)
Farmerline
Fisheries Department, Ministry of Food & Agriculture
Kwame Nkrumah University of Science and Technology
Ministry of Agriculture Fisheries Directorate
Pilot Aquaculture Center
University for Development Studies
Water & Sewage Company
Water Research Institute's Aquaculture Research Development Center

Guatemala
San Carlos University

Guyana
Anna Regina Fish Culture Station
Guyana Department of Fisheries
Guyana School of Agriculture
Maharaja Oil Mill
Mon Repos Aquaculture Center, Department of Fisheries
National Aquaculture Association of Guyana
Trafalgar Union Women's Cooperative
University of Guyana
USAID Farmer-to-Farmer Program
USAID/GTIS Program
Von Better Aquaculture

Honduras
Centro Nacional de Investigación Piscícola El Carao
Escuela Agrícola Panamerican
Laboratorio de Calidad de Agua La Lujosas
Secretaría de Agricultura y Ganadería
Zamorano University

Indonesia
Indonesian Department of Fisheries
Ladong Fisheries College
Ujung Batee Aquaculture Center

International
Asian Fisheries and Aquaculture Forum
Heifer International
International Water Management Institute of the Consultative Group on International Agriculture Development (CGIAR)
Food & Agriculture Organization of the United Nations
Gender in Aquaculture and Fisheries for the Asian Fisheries Society
International Symposium on Tilapia in Aquaculture
The International Institute of Fisheries Economics & Trade
Sustainable Aquaculture Research Networks in Sub Saharan Africa
World Aquaculture Society
The World Bank

Kenya
Egerton University
Karatina University
Kenya Business Development Services
Kenya Marine & Fisheries Research Institute
Kenya Ministry of Fisheries Development
Ministry of Agriculture, Livestock, and Fisheries
Moi University
Mwea Fish Farm
National Investment Center
Nyanchwa College of Science and Technology
Sagana Aquaculture Center
University of Nairobi
University of Eldoret
Women in Fishing Industry Project Kenyatta University

Kenya, Tanzania, Uganda
Lake Victoria Fisheries Organization (Kenya, Tanzania, Uganda)

Kenya, Tanzania, Uganda, Rwanda, Burundi
Lake Victoria Environmental Management Project (Kenya, Tanzania, Uganda, Rwanda, Burundi)
FishAfrica

Lebanon
American University of Beirut

Malawi
Bunda College, Lilongwe

Malaysia
WorldFish Center

Mali
Assemblee Permanente des Chambres d'Agriculture du Mali
Direction Nationale de la Peche
Ministere de L'Elvage et de la Peche
Rural Polytechnic Institute for Training & Applied Research
The Permanent Assembly of Chambers of Agriculture
USAID Mali

Mexico
Centro de Investigacion de Alimentacion y Desarrollo (Research Center for Food & Development)
Centro de Transferencia Tecnologica Para La Acuicultura
Comite Estatal de Sanidad Acuicola de Sinaloa
Cooperativa Pesquera San Ramon
Federation of Shrimp Cooperatives
Instituto Nacional de Investigaciones Forestales y Agropecuarias
Instituto Nacional de Investigaciones Forestales y Agropecuarias
Instituto Sinaloense de Acuacultura
Instituto Technologico del Mar
Mariano Matamoros Hatchery
Regional Center of Education and Qualification for Sustainable Development
Research Center for Food & Development
Secretariat of Agricultural Development for the State of Tabasco
Sinaloa State Fisheries Department
The Autonomous University of Sinaloa-Culiacan
The Autonomous University of Sinaloa-Mazatlan
Universidad Autónoma de Sinaloa–Culiacán
Universidad Autónoma de Sinaloa–Mazatlán
Universidad Autónoma de Tamaulipas
Wetlands Conservation Program
Universidad Juarez Autónoma de Tabasco
Women's Oyster Culture Cooperatives of Nayarit
Women's Oyster Culture Cooperatives of Puerto Penasco

Nepal
Agriculture and Forestry University
Annapurna Higher Secondary School
Center for Aquaculture Research and Production
Directorate of Fisheries Development
Institute of Agriculture and Animal Science
Janata Higher Secondary School
Kathar Higher Secondary School
Mishrit Cooperative
Nepal Agricultural Research Council
Nepal Fish Farmer's Association
Nepal Fisheries Society
Nepal Higher Secondary School
Prithivi Secondary School
Rural Integrated Development Society
Rural Integrated Development Society-Nepal
Shree Chandeshwory Secondary School
Sundardeep Women Fish Farmer's Cooperative
Winrock International

Nicaragua
Center for Research for Aquatic Ecosystems and Aquaculture/Central American University
Nicaraguan Ministry of the Environment

Peru
Fondo Nacional del Desarrollo Pesquero
Instituto de Investigaciones de la Amazonia Peruana
Universidad Nacional Mayor de San Marcos

Philippines
Bureau of Fisheries and Aquatic Resources
Central Luzon State University
Department of Agriculture
Genetically Improved Farmed Tilapia Foundation International, Inc.
Mindanao State University

Southeast Asian Fisheries Development Center - Aquaculture Division
University of the Philippines Visayas (Institute of Fish Processing Technology)
West Visayas State University

Puerto Rico
University of Puerto Rico

South Africa
Department of Water Affairs & Forestry
Stellenbosch University
Water Research Commission

Tanzania
Institute of Marine Sciences, University of Dar es Salaam
Kingorwila National Fish Center
Mbegani Fisheries Development Centre
Ministry of Natural Resources and Tourism-Aquaculture Division
Nyegezi Fisheries Institute
Sokoine University of Agriculture
Tanzania Fisheries Research Institute
University of Dar es Salaam
Western Indian Ocean Marine Science Association

Thailand
CNN Aquaculture and Supply Company
Department of Fisheries
FAO in Asia-Pacific
Kasetsart University
Network of Aquaculture Centers in Asia

The Netherlands
Intervet-Schering Plough Animal Health
Tilapia International Foundation

Uganda
Bidii Fish Farmers
Blessed Investment Fish Farm
Grameen Foundation
Gulu University
Jinja United Group Initiative for Poverty Alleviation & Economic Development
Makerere University
Namuyenge Mixed Farmers Ltd
National Fisheries Resources Research Institute-Aquaculture Research and Development Center
Source of the Nile Fish Farm
Walimi Fish Cooperative Society Ltd.

United Kingdom
Forum for the Future
UK Department for International Development
University of Stirling

US
American Soybean Association
AmeriSci International
Aquaculture without Frontiers
Bemidji State University
Brooklyn College
Coastal Resources Center-University of Rhode Island
Cornell University
Cultural Practice LLC
Delaware State University
Feed the Future Innovation Labs
Fish Farmacy
Fisheries Industry Technology Center-University of Alaska
Florida International University
Global Aquaculture Alliance
Goldman Sachs
Goosepoint Oyster Inc.
Institute for Agriculture and Trade Policy, Minnesota
Louisiana State University
Michigan State University
Montana State University
National Oceanic and Atmospheric Administration – International Sea Grant
National Sea Grant Program Extension Office
Nutrition Innovation Lab, Tufts University
Ohio State University
Oxfam America
Pacific Shellfish Growers Association
Partners of the Americas
Peanut CRSP
Shrimp Improvement Systems
Southern Illinois University at Carbondale
Sustainable Management of Watershed CRSP
Texas A&M University
Texas Parks & Wildlife Department
Texas Sea Grant
Texas Tech University
U.S. Food & Drug Administration
University of California, Davis
University of Delaware

University of Georgia
University of Hawaii at Manoa
University of Oklahoma
University of Tennessee
University of Texas
University of the Virgin Islands
US Department of Agriculture
US Department of Commerce-NOAA
US Fish and Wildlife Service - Bozeman Fish Technology Center
US Geological Survey
US-Mexico Aquaculture TIES Program
USAID Sustainable Coastal Communities & Ecosystems Program (SUCCESS)
USAID-Micro, Small & Medium Enterprises-Aquaculture-DAI
World Wildlife Fund

Venezuela
BIOTECMAR C.A.

Vietnam
An Giang Department of Agriculture and Rural Development
Can Tho University
Dong Nai Fisheries Company
Nong Lam University (University of Agriculture and Forestry)
Research Institution for Aquaculture No. 1
University of Agriculture and Forestry (Nong Lam University)
World Wildlife Fund in Asia

ACRONYMS

ABF	Air-Breathing Fishes
ACRSP	Aquaculture Collaborative Research Support Program
AFS	Asian Fisheries Society
AFU	Agriculture and Forestry University
AIARD	Association for International Agriculture & Rural Development
ANAF	Aquaculture Network for Africa
AquaFish IL	The Feed the Future Innovation Lab for Collaborative Research on Aquaculture & Fisheries (Formerly Aquaculture & Fisheries CRSP)
AU	Auburn University
BAU	Bangladesh Agricultural University
BFS	Bureau for Food Security
BMA	Production System Design and Best Management Alternatives
BMP	Best Management Practice
CESAIN	Center of Excellence on Sustainable Agricultural Intensification and Nutrition
CGIAR	Consultative Group on International Agricultural Research
CRSP	Collaborative Research Support Program
CTU	Can Tho University
DTAP	Development Theme Advisory Panel
EdOpNet	Educational Opportunities Network
EPAC	External Program Advisory Council
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FMIS	Fish Market Information System
FSV	Food Safety, Post-Harvest, and Value-Added Product Development
FTF	Feed the Future
FTFMS	Feed the Future Monitoring System
FY17	Fiscal Year 2017 (01 October 2016 – 30 September 2017)
GAF	Gender in Aquaculture and Fisheries
GMO	Genetically Modified Organism
HACCP	Hazard Analysis and Critical Control Point
HARVEST	Helping Address Rural Vulnerabilities and Ecosystem Stability
HC	Host Country
HHI	Human Nutrition and Human Health Impacts of Aquaculture
HICD	Human and Institutional Capacity Development
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome
IA	Impact Assessment
IFReDI	Inland Fisheries Research and Development Institute
IL	Innovation Lab
IMS	Institute of Marine Sciences
IND	Climate Change Adaptation: Indigenous Species Development
IPM	Integrated Pest Management
ISTA	International Symposium on Tilapia in Aquaculture
KNUST	Kwame Nkrumah University of Science and Technology
LWA	Leader-with-Award
M&E	Monitoring and Evaluation
MER	Marketing, Economic Risk Assessment, and Trade
ME	Management Entity
MNE	Mitigating Negative Environmental Impacts

MT	Management Team
NACA	Network of Aquaculture Centres in Asia-Pacific
NaFIRRI	National Fisheries Resources Research Institute
NCE	No Cost Extension
NCSU	North Carolina State University
NEPAD	New Partnership for Africa's Development
NOAA	National Oceanic and Atmospheric Administration
NGO	Non-Governmental Organization
OSU	Oregon State University
PD/A	Pond Dynamics/Aquaculture
PDV	Policy Development
PEEL	Program Evaluation for Effectiveness and Learning
PI	Principal Investigator
PoC	Point of Contact
PU	Purdue University
QSD	Quality Seedstock Development
RCE	Regional Center of Excellence
SARNISSA	Sustainable Aquaculture Research Networks in Sub-Saharan Africa
SIIL	Sustainable Intensification Innovation Lab
SIS	Small Indigenous Species (of fish)
SFT	Sustainable Feed Technology and Nutrient Input Systems
SSA	Sub-Saharan Africa
UC	University of Connecticut – Avery Point
UM	University of Michigan
US	United States
USAID	United States Agency for International Development
WAS	World Aquaculture Society
WIOMSA	Western Indian Ocean Marine Science Association
WIZ	Watershed and Integrated Coastal Zone Management

I. EXECUTIVE SUMMARY

The mission of the *Feed the Future Innovation Lab for Collaborative Research on Aquaculture & Fisheries* (*AquaFish Innovation Lab* or *AquaFish IL*) is to enrich livelihoods and promote health by cultivating international multidisciplinary partnerships that advance science, research, education, and outreach in aquaculture and fisheries. The United States Agency for International Development (USAID) looks to the AquaFish Innovation Lab to "develop more comprehensive, sustainable, ecological and socially compatible, and economically viable aquaculture systems and innovative fisheries management systems in developing countries that contribute to poverty alleviation and food security." The AquaFish IL began on 30 September 2006 at Oregon State University (OSU); was in hiatus while under a delayed agency review cycle from October 2011 to March 2013; and was invited to propose a 5-year Phase II program, which was awarded on 27 March 2013. Originally scheduled to end 29 March 2018, the AquaFish IL received a no-cost extension in February 2018, carrying the program to a 28 September 2018 closedown.

The AquaFish Innovation Lab Twelfth Annual Report described activities and accomplishments of the AquaFish IL from 01 October 2017 to 28 September 2018 (FY18). During this reporting period, 18 Host Country Institutions in eight countries and 12 US universities engaged in collaborative research focused on increasing food security, income, and household health of poor and vulnerable populations and building human and institutional capacity through research, technology development, and training students and stakeholders at all levels. Five research projects are integrated across four interrelated themes:

A. Improved Human Health and Nutrition, Food Quality, and Food Safety
B. Income Generation for Small-Scale Fish Farmers and Fishers
C. Environmental Management for Sustainable Aquatic Resources Use
D. Enhanced Trade Opportunities for Global Fishery Markets

The AquaFish Innovation Lab builds upon successes from Phase I (2006-2013), when it was functioning as the AquaFish Collaborative Research Support Program (AquaFish CRSP), by strengthening longstanding collaborative partnerships, establishing new connections, expanding promising research, and maintaining alignment with the US Government's Feed the Future (FTF) Initiative. Phase II Investigations across five projects focus on improving sustainability of aquaculture through the development of innovative technologies and outreach techniques that enhance the sustained well-being of the poor. In FY18, the AquaFish IL completed 24 investigations under Implementation Plan 2016-2018 and six investigations under Implementation Plan 2013-2015, focusing on maximizing impacts and building capacity in host countries. Since FY18 was the final year of the award, much effort was invested in successfully completing research, providing deliverables, and finalizing project-level exit strategies that allow the host countries to continue to build on and carry work forward in a self-reliant, sustainable way.

As part of USAID's Bureau for Food Security (BFS) *Feed the Future Food Security Innovation Center*, AquaFish Innovation Lab Phase II operates under the *Program for Research on Nutritious and Safe Foods*. The AquaFish IL has adapted its research portfolio to emphasize the importance of sustainable aquaculture and fisheries on human nutrition while addressing broader food security issues. Human nutrition is a unifying thread in AquaFish IL research and partners are helping meet nutritional needs and increase food security by developing sustainable aquaculture technologies and practices. In FY18,

AquaFish IL in Vietnam and Cambodia completed analysis of a food and nutrition survey to determine the nutrient diversity of commonly consumed fish species in the region. The results will guide policy and programs to improve household nutrition and promote more diversified nutrient uptake. AquaFish IL in Bangladesh concluded testing optimal nutritional absorption and growth in tilapia. This research improves production efficiency of tilapia by reducing feed costs while potentially enhancing the nutritional composition of tilapia, leading to enhanced food security and food safety.

AquaFish Innovation Lab is dedicated to improving gender equity and equality in the aquaculture and fisheries sectors. For example, the Sunderdeep Women's Fish Farmer's Cooperative in Nepal partnered with the AquaFish IL through participation in a periphyton enhancement study to determine effective carp polyculture methods. This research targets local women who are often left to maintain the household and care for the family when their husbands must seek employment outside of the home and often outside of Nepal. Involving women in these activities helps improve household nutrition and increases the sustainability and enhancement of household fish pond production by teaching them best management practices. Women are supported in all facets of AquaFish Innovation Lab operations, including as administrators, researchers, students, long- and short-term trainees, advisors, and stakeholders. The AquaFish IL sets a benchmark of 50% participation by women in all types of training activities. For FY18, women represented 44% of participants in short-term trainings and 48% of long-term degree-seeking students. Providing support to women through long-term educational training increases their involvement in aquaculture early in their academic careers, creates connections and builds networks that can be accessed far into the future, and prepares them to serve in lead research and administrative positions for long-lasting gender equity.

The AquaFish Innovation Lab collaborates with international partners in order to build human and institutional capacity in developing countries and to ensure that sustainable solutions are appropriate and applicable to regional conditions. AquaFish IL's HICD work focuses on short- and long-term trainings; institutional strengthening; and collaborative partnerships with governmental research institutions, public and private sectors, and non-governmental organizations (NGOs). In FY18, 22 short-term trainings were held in four AquaFish IL Host Countries, reaching a total of 786 participants. In addition, the AquaFish IL supported and mentored 151 long-term students at 19 different institutions in nine countries. The AquaFish IL presented numerous student awards and sponsorships in FY18, including: three winners of the *AquaFish/USAS Best Student Abstract Award* and five winners of the *AquaFish Student Abstract Award for International Development*, both of which were presented at Aquaculture America 2018 in Las Vegas; three winners of the *AquaFish Best Student Papers on Aquaculture Economics* at the International Institute of Fisheries Economics & Trade (IIFET) conference in Seattle; attendance of three OSU undergraduate students at the American Fisheries Society Oregon Chapter meeting in Eugene, OR; and attendance of three undergraduate students and one grad student from OSU's College of Agricultural Sciences for the 54th Annual Association for International Agriculture & Rural Development (AIARD) conference in Washington, DC. AquaFish IL HC institutions continued to build capacity in FY18 through the development of curriculum and degree programs in aquaculture and fisheries sciences. Furthermore, AquaFish Innovation Lab HC partners at these institutions continue to excel in their fields and are being recognized as experts in aquaculture and fisheries. For example, Dr. Steve Amisah, Provost of the College of Agriculture and Natural Resources at Kwame Nkrumah University of Science and Technology, was appointed by the President of Ghana as a Member of the Board of the Fisheries Commission of Ghana in FY18.

AquaFish Innovation Lab researchers continued to actively disseminate results to stakeholders globally, including through presentations at professional conferences and publications in peer-reviewed and trade journals. In FY18, AquaFish IL participants at six international scientific conferences and meetings in three countries made 96 presentations and published 19 articles in peer-reviewed academic journals, books, and trade magazines. At the Aquaculture America 2018 (AA2018) conference in Las Vegas,

AquaFish Innovation Lab Director Dr. Hillary Egna chaired an all-day technical session focusing on AquaFish IL research results, covering topics such as development of alternative feed ingredients and impacts of aquaculture on household nutrition. The AquaFish Innovation Lab also held a meeting in FY18 (in conjunction with AA2018) and hosted over 30 international partners at OSU to help them connect with faculty who share their research interests. Dr. Egna and Isaac Omiat (an Ugandan colleague) presented AquaFish IL work and participated as panelists at the Feed the Future Innovation Lab meeting in Kampala, Uganda, in May. A farewell meeting was held in conjunction with AQUA 2018, a flagship conference occurring every six years to gather all major global aquaculture associations together. In addition to multiple oral and poster presentations at AQUA 2018, the AquaFish IL organized four innovative technical panel sessions, involving 33 people on the following topics: 1) Shared Lessons for Low Aquaculture Food Producing Countries; 2) What is Needed Now in 2018 to Make Aquaculture a Vital Enterprise for Smallholders in Africa; 3) Emerging Technologies from AquaFish Innovation Lab Research; and 4) Shared Lessons from High-Producing Asian and LAC Countries for High-Producing African Countries. These activities further complement the AquaFish Innovation Lab mission and expand the network of researchers dedicated to sustainable aquaculture and fisheries innovations.

AquaFish IL partners participate in a panel discussion at AQUA 2018 in Montpellier, France.

II. PROGRAM ACTIVITIES AND HIGHLIGHTS

In FY18, the AquaFish Innovation Lab conducted research in developing countries, continued building and strengthening international multidisciplinary partnerships, and disseminated research results at international conferences and workshops, and in scientific journals, books, and trade magazines. AquaFish IL researchers and Management Team staff also worked diligently in the final year to successfully conclude all research and ensure that all deliverables were completed.

Five US universities (Auburn University, North Carolina State University, Purdue University, University of Connecticut – Avery Point, and University of Michigan) were selected in 2013 to partner with OSU to conduct work in nine countries in Africa and Asia. Under these five projects, the AquaFish IL partnered with seven additional US universities and 18 institutions and organizations in Africa and Asia in FY18 to work on and complete a total of 30 investigations (24 from IP 2016-2018 and six continuing from IP 2013-2015) focusing on two main themes: *Integrated Production Systems*, and *People, Livelihoods, and Ecosystem Interrelationships*. A sixth research project based at Michigan State University and focusing on Burma was initiated in 2016.

Notable AquaFish IL research in FY18 included the expansion of the Fish Market Information System (FMIS) in Ghana to include prices of marine species at selected landing sites. The FMIS now delivers information in five languages (English and four local Ghanaian languages). A similar mobile phone technology developed in Uganda by the AquaFish Innovation Lab is now available on three platforms (smartphones, basic cell phones, and on the internet). These types of technologies further improve marketing efficiencies and access throughout the value chain.

In FY18, AquaFish IL partners completed research addressing ways to reduce operational costs while maintaining profitable yields in FY18. Projects in Bangladesh and Nepal studied a variety of polyculture methods and species. By raising more than one species of fish in the same production system, farmers can increase household income and access to nutritious and diverse foods. In Tanzania, AquaFish IL researchers finalized work to develop locally-sourced and cost-effective protein from invertebrates for use in fish feeds. These researchers were able to extend this technology to farmers through trainings on best management practices for on-farm invertebrate production.

Strengthening human and institutional capacity is a primary objective for the AquaFish IL and is accomplished through a variety of ways, including collaborative partnerships, resource and facility sharing, support of degree-seeking students, curriculum development, recruitment and retention of students and faculty, short-term training courses, recognition of outstanding achievements, and professional development opportunities at international aquaculture and fisheries conferences. In FY18, the AquaFish IL supported 151 long-term degree students (48% women) at 19 institutions in nine countries. The AquaFish IL conducted 22 short-term trainings, reaching 786 people, with women representing 44% of the trainees. In addition, the AquaFish IL chaired an all-day technical session at Aquaculture America 2018 in Las Vegas and offered awards to seven students who presented at the conference.

In AquaFish IL's final year, the AquaFish IL Director, staff, and several AquaFish IL partners from Cambodia and Vietnam attended the first ever International Sustainable Agricultural Intensification and Nutrition conference in Phnom Penh, Cambodia, hosted by the Feed the Future Innovation Lab for

Sustainable Intensification (SIIL). During the conference, AquaFish IL presented research and chaired a session, and visited CESAIN Technology Parks and other USAID-funded sites within Cambodia. This conference allowed USAID IL partners to network with colleagues working in the same region doing similar work and can help foster new partnerships.

AquaFish IL partners visit CESAIN Technology Parks and other USAID-funded sites in Cambodia during the first ever International Sustainable Agricultural Intensification and Nutrition conference.

The AquaFish IL continued to disseminate research results and recommendations through presentations at national and international conferences as well as in peer-reviewed and trade publications. In FY18, AquaFish IL researchers made 96 presentations at scientific and professional conferences and produced 19 publications for journals, books, and trade magazines. Since 2006, AquaFish IL researchers have published more than 325 publications on program-related research. These outreach activities further expand collaborative networks and increase AquaFish Innovation Lab impacts throughout the world.

III. KEY ACCOMPLISHMENTS

AquaFish Innovation Lab outputs and achievements in research, capacity building, information dissemination, and gender integration are measured relative to qualitative and quantitative targets identified in the USAID approved Monitoring and Evaluation (M&E) Plan and Feed the Future Indicators and Monitoring System (FTFMS). Key accomplishments in FY18 under the AquaFish IL Leader Award are highlighted below.

Research and Technology Development

Twenty-three innovative aquaculture technologies were at varying stages of development in Africa and Asia in FY18. In developing these technologies, AquaFish IL projects involved 45 food security enterprises, producer organizations, women's groups, trade and business associations, and community-based organizations. AquaFish IL research in Uganda and Ghana developed cell phone applications and information networks with fish farmers and government employees to address aquaculture information needs, improve efficiencies in the value chain, and reduce post-harvest loss. The mobile application in Uganda is available on three platforms—smartphones, basic cell phones, and on the internet – with eight training modules, while in Ghana the system has expanded beyond tilapia and catfish to include marine fishes and markets in five languages (English, Twi, Ga, Ewe, and Fante).

Research and technology development in FY18 has also continued on the development of alternative feeds and feeding practice. To improve production efficiency of tilapia, AquaFish IL research in Bangladesh built on past studies that successfully reduced feeds by testing the effectiveness of nutritional conditioning for optimal nutritional absorption and growth. During on-station trials in tanks, growth data indicated that tilapia fry fed reduced protein diets for seven or 14 days may improve overall growth of fish later in life, but on-farm trails in ponds suggest that early protein restriction only enhanced feed conversion ratios. Limited protein early in life has little apparent effect on fish gut microbiome, but the diversity of microbes is dynamic and changes over time. Results indicated that limiting protein early in life could reduce feeding costs and enhance production if performed in clean tank systems. This research has the potential to lead to the development of probiotic bacterial supplements for feeds to improve fish health and growth and contribute to food security. In Vietnam and Cambodia, researchers determined that diets supplemented with 500 mg of ascorbic acid per kg of feed resulted in the highest survival rate, highest yield of fish, best feed conversion ratio, and resulted in the highest profit margin. In Tanzania, researchers built on FY16 work in developing affordable, locally-sourced fish-feeds from invertebrates, specifically housefly maggot meal. Research determined the optimal substrates for growing the maggot meal were cattle intestine and poultry dung.

Human and Institutional Capacity Building

Since program inception in 2006, the AquaFish IL has fostered linkages with over 250 institutions globally. In FY18, the AquaFish Innovation Lab had a total of 77 active linkages, including formal (funded) institutional or individual partnerships with 38 organizations in 14 countries, and an additional 39 informal (unfunded) collaborators. The AquaFish IL supported 151 students enrolled in long-term degree programs at US and HC institutions this fiscal year. Twenty-two short-term training events were held, with a total of 786 participants, and included workshops, on-farm trainings, and train-the-trainer events to target a range of audiences. Additionally, the AquaFish IL worked with OSU filmmakers in FY18 to create videos showcasing examples of excellence in capacity building over the life of the AquaFish IL.

In FY18, the AquaFish IL also helped build the capacity of partnering Host Country Institutions, their local communities, and more broadly, the aquaculture sector in their region. Researchers at Nepal's Agriculture and Fisheries University helped build capacity of their surrounding community by facilitating farmer-to-farmer exchange of information, training teachers and students about carp culture in ponds located on-site at secondary schools, and through collaboration with women's fish farmer groups. In Kenya, AquaFish IL researchers from the University of Eldoret designed a small-scale aquaponics system, specifically for urban and/or water deficient scenarios, and it is now used as an educational tool. Over 200 stakeholders have viewed the small-scale system. In Bangladesh, over 120 farmers participated in the research through on-farm trials and group discussions. The farmers learned how to test new ideas, manage and harvest aquaculture ponds and dyke vegetable farming, collect and track data, and measure seafood yields. The activities have greatly promoted the entrepreneurship of the communities as well as improved household nutrition and their capacity to farm fish. AquaFish IL researchers based at Michigan State University utilized existing datasets and explored the importance of inland fisheries in Burma, both wild-capture and aquaculture, in supplying micronutrients to the Burmese diet and their role in food security across the country. AquaFish IL researchers were able to demonstrate the importance of species diversity and the need for nutrition-sensitive approaches and monitoring trends in household fish consumption among the population, especially along the urban-rural continuum.

AquaFish Host Country PI Dr. Hien of Can Tho University helps sample snakehead from a hapa in Vietnam.

Information Dissemination

The AquaFish Innovation Lab has disseminated programmatic findings to stakeholders through multiple avenues including the AquaFish IL website (aquafish.oregonstate.edu), social media sites, newsletters, conference presentations, and trade magazines publications. Additionally, nine issues of *EdOpNet* (education opportunities in aquaculture and fisheries-related fields) reached over 1,700 recipients in FY18. The AquaFish IL encourages researchers to publish findings in peer-reviewed journals in order to reach the broader research community, and to advance aquaculture science. The AquaFish IL scientific strength and accomplishments are evidenced by over 325 peer-reviewed publications on AquaFish IL-supported research and data since program inception in 2006, 19 of which were published in FY18. Information was also shared among AquaFish IL project partners in FY18 through a technical session hosted by the AquaFish IL Director at the Aquaculture America 2018 (AA 2018) conference in Las

Vegas, Nevada, USA. AquaFish Innovation Lab US and HC partners presented on findings to the broader scientific community at AA 2018. This venue provided opportunities to showcase AquaFish IL work and to improve upon research and capacity building efforts through peer feedback.

AquaFish IL partners tour the Willow Beach National Fish Hatchery in Arizona prior to Aquaculture America 2018 conference.

Gender Integration

The AquaFish IL continues to collect and analyze gender-disaggregated data in order to gauge gender inclusiveness and success. Strategies for engaging women are adapted, as needed, as the AquaFish IL works towards the 50% benchmark for training women in formal and informal education, and for retaining women scientists and administrators in all facets of AquaFish IL operations. In FY18, the AquaFish IL nearly met this 50% benchmark for supporting long-term trainees at degree granting institutions in the US and host countries with women representing 48% of the long-term trainees. Women represented 44% of participants in AquaFish IL-sponsored short-term trainings. AquaFish IL Director, Dr. Hillary Egna, is a founding member of the Gender in Aquaculture and Fisheries Section (GAF) of the Asian Fisheries Society and helped support GAF in pre-conference planning and strategy formulation for the organization. Beyond the formal capacity building effort, gender integration continues to be a cross-cutting theme of the AquaFish IL research portfolio. In Zanzibar, work continued to empower coastal communities through participation in spat collection experiments. As women play a significant role in the pearl culture industry, they were involved in experiments and were provided training on entrepreneurship skills. These activities continue to help empower women in building the economies of the Bweleo and Nyamanzi villages and further improve their household livelihoods. In Nepal, 15 women from the Sunderdeep Women's Fish Farmer's Cooperative joined 12 men and three additional women from the Mishrit Cooperative to participate in a periphyton enhancement study. The group tested five different substrates for boosting periphyton growth and improving in-pond productivity and determined that fish production, gross margins, and gross returns for the ponds with periphyton substrates were higher than the controls. The AquaFish IL has also empowered a woman professor at Yangon University in Burma to lead efforts towards evaluating and enhancing faculty and institutional capacity in aquaculture. Given that over 90% of professors at Yangon University are women, faculty development has the potential to reach many women in Burma and to more broadly improve gender integration in the aquaculture sector in Southeast Asia.

IV. RESEARCH PROGRAM OVERVIEW AND STRUCTURE

The AquaFish Innovation Lab is managed to achieve maximum program impacts, particularly for small-scale farmers and fishers, in Host Countries and more broadly. AquaFish IL program objectives address the need for world-class research, capacity building, and information dissemination. Specifically, the AquaFish IL strives to:

- Develop sustainable end-user level aquaculture and fisheries systems to increase productivity, enhance international trade opportunities, and contribute to responsible aquatic resource management;
- Enhance local capacity in aquaculture and aquatic resource management to ensure long-term program impacts at community and national levels;
- Foster wide dissemination of research results and technologies to local stakeholders at all levels, including end-users, researchers, and government officials; and
- Increase Host Country capacity and productivity to contribute to national food security, income generation, and market access.

The overall research context for the projects described in this Annual Report is poverty alleviation and food security improvement through sustainable aquaculture development and aquatic resources management. Discovery through research and technology development forms the core of projects. Projects also integrate institutional strengthening, gender, outreach, and capacity building through activities such as training, formal education, workshops, extension, and conferences to support the scientific research being conducted.

Projects focus on one or two USAID-eligible countries within a region, and may include activities in nearby countries within the same region. All projects received USAID country-level concurrence prior to award.

GLOBAL AQUAFISH INNOVATION LAB PROJECT THEMES (GOALS)

A. Improved Human Health and Nutrition, Food Quality, and Food Safety
B. Income Generation for Small-Scale Fish Farmers and Fishers
C. Environmental Management for Sustainable Aquatic Resources Use
D. Enhanced Trade Opportunities for Global Fishery Markets

Each project focuses on one primary AquaFish IL theme, yet integrates all four themes to achieve a systems approach. The global themes of the AquaFish IL are cross-cutting and address several specific USAID policy documents and guidelines.

AQUAFISH INNOVATION LAB RESEARCH PROJECTS

All projects are organized around ten specific areas of inquiry called Topic Areas. Current projects contain between four and eight investigations. Project investigations focus on more than one topic area in

describing aquaculture research that will improve diets, generate income for smallholders, manage environments for future generations, and enhance trade opportunities.

A systems approach requires that each AquaFish IL project integrate topic areas (listed below and described later in this Section) from the following two categories:

Integrated Production Systems

- Production System Design & Best Management Alternatives (BMA)
- Sustainable Feed Technology (SFT)
- Climate Change Adaptation: Indigenous Species Development (IND)
- Quality Seedstock Development (QSD)

People, Livelihoods, and Ecosystem Interrelationships

- Human Nutrition and Human Health Impacts of Aquaculture (HHI)
- Food Safety, Postharvest, and Value-Added Product Development (FSV)
- Policy Development (PDV)
- Marketing, Economic Risk Assessment, and Trade (MER)
- Watershed and Integrated Coastal Zone Management (WIZ)
- Mitigating Negative Environmental Impacts (MNE)

RESEARCH PROJECT STATISTICS

The AquaFish IL takes a systems approach, with 52% of investigations categorized as *Integrated Production Systems* and 48% as *People, Livelihoods, and Ecosystem Interrelationships* for Phase I and II research projects (Table IV-1).

Table IV-1. AquaFish IL research project investigations by Systems Approach and Topic Areas for Phase I and Phase II.

		Number of Investigations					
		Phase I		Phase II			
Systems Approach	**Topic Area**	**2007-2009**	**2009-2012**	**2013-2015**	**2016-2018**	**Total**	**Percent of Total**
Integrated Production Systems							
	Production System Design & Best Management Alternatives (BMA)	4	13	6	5	28	17%
	Sustainable Feed Technology (SFT)	6	7	8	3	24	15%
	Climate Change Adaptation: Indigenous Species Development (IND)	4	10	4	4	22	13%
	Quality Seedstock Development (QSD)	2	5	2	2	11	7%
	Subtotal	***16***	***35***	***20***	***14***	***85***	***52%***
People, Livelihoods, and Ecosystem Interrelationships							
	Human Nutrition and Human Health Impacts of Aquaculture (HHI)	5	2	4	5	15	10%
	Food Safety, Post Harvest, and Value-Added Product Development (FSV)	1	3	0	2	6	4%
	Policy Development (PDV)	3	8	1	1	13	8%
	Marketing, Economic Risk Assessment, and Trade (MER)	4	10	6	2	22	13%
	Watershed and Integrated Coastal Zone Management (WIZ)	2	3	1	0	6	4%

Mitigating Negative Environmental Impacts (MNE)	7	7	1	2	17	10%
Subtotal	***22***	***33***	***13***	***11***	***79***	***48%***
Total	**38**	**68**	**33**	**26**	**165**	

In FY18, 26 investigations were underway as part of the 2016-2018 Implementation Plan, plus six additional investigations were continued from the 2013-2015 Implementation Plan. A total of eight countries, 13 US Universities, and 18 HC institutions are involved in formal funded partnerships as part of these investigations, and an additional three HC partners are involved through the AquaFish IL advisory panels.

USAID also encourages the AquaFish IL to address biodiversity conservation and non-GMO biotechnology solutions to critical issues in aquaculture. Each overall project describes a comprehensive development approach to a problem. Projects were formed around *core program components*, as identified by USAID: a systems approach; social, economic, and environmental sustainability; capacity building and institution strengthening; outreach, dissemination, and adoption; and gender integration.

AQUAFISH INNOVATION LAB TOPIC AREAS

Topic areas pertain to aquaculture and the nexus between aquaculture and fisheries. Some of the following topic areas overlap and are interconnected. Each investigation identifies a single topic area that best describes it. The text under each topic area is provided for illustrative purposes and is not prescriptive.

Integrated Production Systems

- ***Production System Design & Best Management Alternatives (BMA)***
  Aquaculture is an agricultural activity with specific input demands. Systems need to be designed to improve efficiency and/or integrate aquaculture inputs and outputs with other agricultural and non-agricultural production systems. AquaFish IL research must benefit smallholder or low- to semi-intensive producers, and should focus on low-trophic species for aquaculture development. Design systems to limit negative environmental impacts, to improve overall fish health, and optimize carrying capacity. Interventions for disease and predation prevention must adopt an integrated pest management (IPM) approach and be careful to consider consumer acceptance and environmental risk of selected treatments. Innovative research is encouraged on: recirculating and aquaponics systems for supplying aquatic products to denser marketplaces in urban and peri-urban areas; integrated systems using shellfish, seaweeds, or other plants and animals; and new solutions for aeration, cold storage, and pond operations involving solar or other novel energy sources.

- ***Sustainable Feed Technology and Nutrient Input Systems (SFT)***
  Methods of increasing the range of available ingredients and improving the technology available to manufacture and deliver feeds are critical research themes. Better information about fish nutrition can lead to the development of less expensive and more efficient feeds. Investigations on successful adoption, extension, and best practices for efficient feed strategies that reduce the "ecological footprint" of a species under cultivation are encouraged. Research on soil-water dynamics and natural productivity to lessen feed needs were fundamental to the Pond Dynamics/Aquaculture (PD/A) and Aquaculture Collaborative Research Support Program (ACRSP); critical new areas of research may be continued, along with outreach to poor farmers using low-cost, no/low-feed technologies. Feed research that lessens reliance on fishmeal/proteins/oils and lowers feed conversion ratios is desired, as is research on feeds (ingredients, sources, regimes, formulations) that result in high quality and safe aquaculture products with healthy nutrition profiles. Complex pond dynamics technologies need to be

simplified for use by new farmers; improved applications of pond dynamics technologies for driving non-fed plankton-driven systems are applicable where access to feeds is expensive or unreliable.

- ***Climate Change Adaptation: Indigenous Species Development (IND)***
  Aquaculture, like agriculture and other human activities, will feel the effects of long-term climate change. Among the myriad challenges, ocean acidification and sea level rise will affect the world's coastal aquaculture operations, much of which occur in poorer countries. Temperature changes will test the resiliency of domesticated varietals. Research challenges involve understanding the adaptive range of these species, and developing cultivation techniques for new species, such as air-breathing fishes. The shifting distribution of global freshwater supplies will pose challenges for the aquaculture industry, small farmers, and the marketplace. Genomics tools may be used to characterize candidate air-breathing species already being evaluated through previous CRSP research. Domestication of indigenous species may contribute positively to the development of local communities as well as protect ecosystems. At the same time, the development of new native species for aquaculture must be approached in a responsible manner that diminishes the chance for negative environmental, economic,
  and social impacts. Research that investigates relevant policies and practices is encouraged while exotic species development and transfer of non-native fishes are not encouraged. A focus on biodiversity conservation and biodiversity hotspots, as related to the development of native species for aquaculture, is of great interest. Aquaculture, done sensitively, can be a means to enhance and restock small-scale capture and wild fisheries resources. (Aquaculture-Fisheries Nexus Topic Area)

- ***Quality Seedstock Development (QSD)***
  Procuring reliable supplies of high quality seed for stocking local and remote sites is critical to continued development of the industry, and especially for small-holder private farms. A better understanding of the factors that contribute to stable seedstock quality, availability, and quantity for aquaculture enterprises is essential. Genetic improvement (e.g., selective breeding) that does not involve genetically-modified organisms (GMOs) may be needed for certain species that are internationally traded. All genetic improvement strategies need to be cognizant of marketplace pressures and trends, including consumer acceptance and environmental impacts. Augmentation of bait fisheries through aquaculture to support capture fisheries is an area of interest, provided there are no net negative environmental effects.

People, Livelihoods, and Ecosystem Interrelationships

- ***Human Nutrition and Human Health Impacts of Aquaculture (HHI)***
  Aquaculture can be a crucial source of protein and micronutrients for improved human health, growth, and development. Research on the intrinsic food quality of various farmed fish for human consumption is needed—this might include science-based studies of positive and negative effects of consuming certain farmed fishes. Patterns of fish consumption are not well understood for many subpopulations. Human health can be negatively impacted by aquaculture if it serves as a direct or indirect vector for human diseases. There is interest in better understanding the interconnectedness of aquaculture production and water/vector-borne illnesses such as malaria, schistosomiasis, and Buruli ulcer and human health crises such as HIV/AIDS and avian flu. Focus on vulnerable populations, women and children, and underserved populations, and assess how any given technology will affect or improve the welfare of these groups. Research or field-testing with schools and nutrition centers is encouraged. (Aquaculture-Fisheries Nexus Topic Area)

- ***Food Safety, Post-Harvest, and Value-Added Product Development (FSV)***
  Ensuring high quality, safe, and nutritious fish products for local consumers and the competitive international marketplace is a primary research goal. Efforts that focus on reducing microbial contamination, hazard analysis and critical control point (HACCP) controls and hazards associated

with seafood processing, value-added processing, post-processing, and by-product/waste development are of interest. Consumers and producers alike will benefit from research that contributes to the development of standards and practices that protect fish products from spoilage, adulteration, mishandling, and off-flavors. Processing waste can claim up to 70% by weight of finfish depending on the species and manner processed, and post-harvest losses can claim around 30%. Partnering with other groups and co-developing outreach techniques to reduce post-harvest losses can significantly contribute to the amount of fish available for consumption, thus, contributing to the nutrition goals of USAID's Feed the Future Initiative. Certification, traceability, product integrity, and other efforts to improve fish products for consumer acceptance and international markets are desired. Gender integration is important to consider as women are strongly represented in the processing and marketing sectors, and throughout much of the value chains. (Aquaculture-Fisheries Nexus Topic Area)

- ***Policy Development (PDV)***
  Policy initiatives that link aquaculture to various water uses to improve human health are needed. Areas of inquiry can include institutional efforts to improve extension related to aquaculture and aquatic resources management; science-based policy recommendations targeting poor subpopulations within a project area, or more broadly (e.g., national aquaculture strategies); methods of improving access to fish of vulnerable populations including children (e.g., school-based aquaculture programs); science-based strategies for integrating aquaculture with other water uses to improve well-being, such as linkages with clean drinking water and improved sanitation. Additionally, social and cultural analyses regarding the impacts of fish farming may yield critical information for informing policy development.

- ***Marketing, Economic Risk Assessment, and Trade (MER)***
  Aquaculture is a rapidly growing industry and its risks and impacts on livelihoods need to be assessed. Significant researchable issues in this arena include cost, price, and risk relationships; domestic market and distribution needs and trends; the relationships between aquaculture and women/underrepresented groups; the availability of financial resources for small farms; and the effects of subsidies, taxes, and other regulations. Understanding constraints across value chains in local, regional, and international markets is of interest, especially as constraints affect competitiveness, market demand, and how to link producers to specific markets. (Aquaculture Fisheries Nexus Topic Area)

- ***Watershed & Integrated Coastal Zone Management (WIZ)***
  Aquaculture development that makes wise use of natural resources is at the core of the AquaFish IL program. Research that yields a better understanding of aquaculture as one competing part of an integrated water use system is of great interest. The range of research possibilities is broad—from investigations that quantify water availability and quality to those that look into the social context of water and aquaculture, including land and water rights, national and regional policies (or the lack thereof), traditional versus industrial uses, and the like. Water quality issues are of increasing concern as multiple resource use conflicts increase under trends toward scarcity or uneven supply and access, especially for freshwater. Ecoregional analysis is also of interest to explore spatial differences in the capacities and potentials of ecosystems in response to disturbances. Innovative research on maximizing water and soil quality and productivity of overall watersheds is of interest. Pollution is a huge concern, as over 50% of people in developing countries are exposed to polluted water sources. Additionally, aquatic organisms cannot adequately grow and reproduce in polluted waters, and aquaculture may not only be receiving polluted waters, but adding to the burden. Rapid urbanization has further harmed coastal ecosystems, and with small-scale fisheries and aquaculture operations in the nearshore, integrated management strategies for coastal areas are also important. (Aquaculture

Fisheries Nexus Topic Area)

- ***Mitigating Negative Environmental Impacts (MNE)***
  With the rapid growth in aquaculture production, environmental externalities are of increasing concern. Determining the scope and mitigating or eliminating negative environmental impacts of aquaculture—such as poor management practices and the effects of industrial aquaculture—is a primary research goal of this program. A focus on biodiversity conservation, especially in biodiversity "hotspot" areas, as related to emerging or existing fish farms is of great interest. Therefore, research on the impacts of farmed fish on wild fish populations, and research on other potential negative impacts of farmed fish or aquaculture operations are needed, along with scenarios and options for mitigation. (Aquaculture-Fisheries Nexus Topic Area)

ENVIRONMENTAL COMPLIANCE

The following USAID environmental restrictions apply to the projects and the overall program:

- Biotechnical investigations will be conducted primarily on research stations in Host Countries.
- Research protocols, policies, and practices will be established prior to implementation to ensure that potential environmental impacts are strictly controlled.
- All training programs and outreach materials intended to promote the adoption of AquaFish IL-generated research findings will incorporate the appropriate environmental recommendations.
- All sub-awards must comply with environmental standards.
- AquaFish IL Projects will not procure, use, or recommend the use of pesticides of any kind. This includes but is not limited to algaecides, herbicides, fungicides, piscicides, parasiticides, and protozoacides.
- AquaFish IL Projects will not use or procure genetically modified organisms.
- AquaFish IL Projects will not use, or recommend for use, any species that are non-endemic to a country or not already well established in its local waters, or that are non-endemic and well established but are the subject of an invasive species control effort.

TERMINOLOGY FOR INVESTIGATIONS

Investigations that generate new information form the core of projects. Each investigation is clearly identified as an experiment, study, or activity, based on the following definitions:

Experiment	A scientifically sound investigation that addresses a testable hypothesis. An experiment implies collection of new data by controlled manipulation and observation.
Study	A study may or may not be less technical or rigorous than an experiment and may state a hypothesis if appropriate. Studies include surveys, focus groups, database examinations, most modeling work, and collection of technical data that do not involve controlled manipulation (e.g., collection and analysis of soil samples from sites without having experiments of hypothesized effect before collection).
Activity	An activity requires staff time and possibly materials but does not generate new information like an experiment or a study. Conference organization, training sessions, workshops, outreach, and transformation and dissemination of information are examples of activities.

Investigations provide a transparent means for evaluating different types of work under the AquaFish IL, be they quantitative, empirical, biologically-based, qualitative, policy-based, or informal. Each project is required to include at least one experiment or study, and at least one outreach activity that focuses on women and/or girls.

GENERAL RESEARCH PRIORITIES

All projects address the following general research priorities:

- Priority Ecosystems
  Inland and coastal ecosystems for aquaculture and aquaculture-fishery nexus topic areas.

- Priority Species
  Low-trophic level fishes, domesticated freshwater fishes, non-finfishes (e.g., bivalves, seaweeds), aquatic organisms used in polyculture and integrated systems, and native species. Food fishes are a priority, but species used for non-food purposes (e.g., ornamental, pharmaceutical) may also be included as a priority if they are a vital part of an integrated approach towards food security and poverty alleviation.

- Target Groups
  Aquaculture farms (small- to medium-scale, subsistence, and commercial) and aquaculture intermediaries, policy makers, and others in host countries.

- Key Partners
  Universities, HC and US government, non-government organizations, private sector, CGIAR, and the USAID Food Security Innovation Center.

V. RESEARCH PROJECT REPORTS

Research project reports summarize achievements, capacity building, and lessons learned from FY18, as reported by AquaFish IL US Project PIs. Reports present progress made during the continuation of work into the 2016-2018 Implementation Plan. The six lead projects address four global themes in an integrated systems approach with a primary focus on one theme as part of the overall AquaFish IL research portfolio.

Theme A – *Improved Human Health and Nutrition, Food Quality, and Food Safety*
Africa Project: Ghana & Tanzania
Asia Project: Burma

Theme B – *Income Generation for Small-Scale Fish Farmers and Fishers*
Africa Project: Kenya & Uganda

Theme C – *Environmental Management for Sustainable Aquatic Resources Use*
Asia Project: Bangladesh
Asia Project: Nepal

Theme D – *Enhanced Trade Opportunities for Global Fishery Markets*
Asia Project: Cambodia & Vietnam

THEME A: IMPROVED HUMAN HEALTH AND NUTRITION, FOOD QUALITY, AND FOOD SAFETY

Africa Project: Ghana & Tanzania
Project Title: *Aquaculture Development and the Impact on Food Supply, Nutrition, and Health in Ghana and Tanzania*

Location
Ghana: Accra, Eastern Ashanti, and Volta Basin
Tanzania: Mbeya, Morogoro, and Zanzibar

For more details on research locations, see the AquaFish Site Descriptions**.**

Project Description
2016-2018 Implementation Plan Investigations
1. Experimental Pond Unit Assessment in Tanzania (16BMA01PU)
2. Increasing Productivity of Nile Tilapia (*Oreochromis niloticus*) through Enhanced Feeds and Feeding Practices (16SFT03PU)
3. Optimizing the Use of Commercial Feeds in Semi-intensive Pond Production of Tilapia in Ghana; From Nursery to Grow-out (16BMA02PU)
4. Fish Consumption and Implications for Household Nutrition and Food Security in Tanzania and Ghana (16HHI02PU)
5. Enhancing the Functionality and Applicability of Fish Market Information System (FMIS) to Marine Artisanal Fisheries in Ghana (16MER01PU)

Continuing Investigations from the 2013-2015 Implementation Plan

1. Spat Collection and Nursery Methods for Shellfish Culture by Women (13QSD01PU)
2. Coastal Women's Shellfish Aquaculture Development Workshop (13BMA01PU)
3. Enhancing the Nutritional Value of Tilapia for Human Health (13SFT02PU)

Principal Project Personnel

Purdue University, US (US Project University) Kwamena Quagrainie – US Project PI **Kwame Nkrumah University of Science & Technology, Ghana (Lead HC Institution)** Stephen Amisah – HC Project PI Daniel Adjei-Boateng – HC Investigator Nelson Agbo – HC Investigator Regina Edziyie – HC Investigator Kwasi Obirikorang – HC Investigator **Institute of Marine Sciences, University of Dar es Salaam, Zanzibar, Tanzania** Narriman Jiddawi – HC Co-PI **University of Hawaii-Hilo, US** Maria Haws – US Co-PI	**University of Arkansas at Pine Bluff, US** Rebecca Lochmann – US Co-PI **Virginia Polytechnic Institute & State University, US** Emmanuel Frimpong – US Co-PI **Sokoine University of Agriculture, Tanzania** Sebastian Chenyambuga – HC Co-PI & Tanzania PoC Hieromin Lamtane – HC Investigator Nazael Madalla – HC Investigator **Farmerline, Ghana** Alloysius Attah – HC Co-PI **Western Indian Ocean Marine Science Association, Zanzibar, Tanzania** Julius Francis – HC Co-PI

Achievements

In FY18, this project continued to take a multifaceted and holistic approach to increasing productivity of tilapia in Ghana and Tanzania. Investigations at the supply-side examined productivity in ponds, alternative fish feed ingredients, and feed management. On the other side of the production chain, investigations examined trends in seafood demand and market information systems and technologies.

In Tanzania, work on alternative fish feeds has continued with explorations of housefly maggot meal as a locally-sourced alternative protein source. Work in FY18 on housefly maggot meal in fish feeds has shown successful feed utilization efficiency, cost competitiveness, and similar growth performance of Nile tilapia (*O. niloticus*) to traditional feeds. Investigating the most appropriate substrate for maggot production, results showed that of the five substrates tested cattle intestine and poultry dung provided the highest production rates.

While alternative feeds were explored in Tanzania, a study in Ghana focused on optimizing the utilization of commercial feeds by evaluating the effect of varying crude protein levels. Results suggest that there is no significant difference in the growth of tilapia using feeds that contain 25%, 28%, and 30% crude protein, but profits were highest while using the 25% crude protein diet. This study also determined that it was most profitable to feed full rations every other day compared to feeding full rations every day or feeding half rations every day.

On the demand-side of the aquaculture value chain, a Seafood Market Information System was developed in Ghana to help open market communication pathways. As a mobile phone-based system, this evolving

technology minimizes the information gaps along the fish value chain and improves efficiencies in fish marketing and the value chain as a whole. Researchers expanded the system to incorporate common marine fishes and markets in five languages (English, Twi, Ga, Ewe and Fante).

A related but separate line of research explored household food security improvements through fish farming and seafood consumption in Ghana and seafood accessibility in Tanzania. Using the Food Consumption Score as a measure of food security, the results of this study showed that fish farming households are more food secure relative to non-fish farming households. The surveys showed that the decision to adopt fish farming is influenced by the wealth of the household, the agro-ecological zone, residing in a peri-urban area, the household size, and per capita income of the household. They also women living in the savannah zone (Northern Ghana) would benefit from adopting fish farming.

Capacity Building

In FY18 in Ghana five MS students continued to be mentored by AquaFish IL researchers at Kwame Nkrumah University of Science and Technology. Two workshops were also organized in Ghana to disseminate project findings to stakeholders. Participants included fish farmers, students, regional fisheries officers, and artisanal fishermen. At Sokoine University of Agriculture in Tanzania, four AquaFish IL-supported students worked toward their Master's degrees and one PhD student was supported at Virginia Tech.

Presentations and Publications

Publications

Amankwah, A., K.K. Quagrainie, and P.V. Preckel. 2018. Impact of aquaculture feed technology on fish income and poverty in Kenya. Aquaculture Economics and Management. Pg. 1-21.

Presentations

Adjei-Boateng, D., A. Aliebe, N.W. Agbo, E.A. Frimpong. 2018. Effect of Different Feeding Strategies on Growth Performance and Economic Returns of Nile Tilapia (*O. Niloticus*) Production in Semi-Intensive System. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

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Madalla, N., L. Hezron, and S. Chenyambuga. 2018. Development of Technique for Mass Production of Housefly (*Musca domestica*) maggots. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Munubi, R., P. Masumbuko, N. Madalla, S. Chenyambuga. 2018. Effects of Pond Water Replacement and Stocking Density on Water Quality, Plankton Abundance and Growth Performance of Tilapia *Oreochromis niloticus*.

Obirikorang, K.A., M.E. Goode, S. Gyamfi, R.E. Edziyie, and S. Amisah. 2018. Digestibility and Ammonia Excretion Rates of Low-Cost Nursery Diets for Nile Tilapia (*Oreochromis niloticus*) Fry. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Obirikorang, K.A., N.W. Agbo, C. Obirikorang, D. Adjei-Boateng, S.E. Ahiave, and P.V. Skov. 2018. Effects of Varying Water Flow Rates on the Growth Performance and Welfare of Nile Tilapia (*Oreochromis niloticus*) Reared in a Recirculating Aquaculture System. [Poster Presentation]. AQUA 2018, Montpellier, France, 25-29 August 2018.

Asia Project: Burma

Project Title: ***Sustainable Inland Fisheries for Burmese Food Security in an Era of Global Change***

Location

USA: Michigan, USA

Project Description

2016-2018 Implementation Plan Investigations

1. Determine the Role of Wild-Caught and Aquaculture-Based Inland Fisheries in Meeting Burma's Nutritional Needs (16HHI05MS)
2. Developing a Conceptual Model to Evaluate the Potential Changes in Inland Food Fish Supple Under Various Global Climate Change Scenarios (16IND04MS)

Principal Project Personnel

Michigan State University William W. Taylor – US Project PI So-Jung Youn – US Investigator Ben Belton – US Investigator	**U.S. Geological Survey** Abigail Lynch – US Investigator Emily Argo – US Investigator Doug Beard – US Investigator

Achievements

The contributions fish make to Burmese food security are not well understood. The AquaFish IL conducted a desk study to analyze Burmese nutrient intake from fish sourced from aquaculture and wild catch fisheries to explore differences in consumption across zones of Burma, wealth quintiles, and along the urban-rural continuum. Using data from the Integrated Household Living Conditions Assessment survey, conducted by the United Nations Development Program, national average fish consumption for 2010 was estimated at 20.72 kg/capita. Analysis of the data showed that inland capture fish are particularly important for consumers in rural areas (who are, on average poorer than those in urban areas), while urban consumers and the wealthy are more likely to eat farmed fish. Dried, fermented, and other preserved fish products accounted for the single largest category of fish consumed in Burma. Fish contributed significantly to daily intake of protein. Disaggregated nutrient contributions at a species level and demonstrated the importance of species diversity and the need for nutrition-sensitive approaches and monitoring trends in household fish consumption among the population and geographical groups described.

In an effort to provide managers, policy makers, and development programs with a means to anticipate changes in inland wild and aquaculture fisheries, a systematic literature review was used to identify the impacts of climate change and applicable management strategies to address these impacts. Through this study, four management areas emerged: barrier vegetation, agriculture to aquaculture conversion, protected areas, and coastal zone management that could be addressed across three levels (business as usual, low intervention, and high intervention). This information facilitated the development of a conceptual model illustrating these different management techniques and resources available as a planning tool for managers.

Capacity Building

Under this project, one MS student, and two PhD students continued their studies at Michigan State University (MSU) with the support of the AquaFish IL. MSU was able to leverage this US-based work to build relationships with and provide professional development opportunities for USGS and Burmese researchers who helped with data acquisition and reliability. Additionally, this research has the potential to assist local Burmese professionals and communities in pursuit of sustainable development and management of their inland wild-caught and aquaculture fisheries, which will provide a greater nutritional resource and improve employment opportunities and greater societal well-being.

THEME B: INCOME GENERATION FOR SMALL-SCALE FISH FARMERS AND FISHERS

Africa Project: Kenya & Uganda

Project Title: ***Aquaculture Development in Kenya and Uganda: Advancing Cost-Effective Technology, Market Assessment, and End-User Engagement***

Location

Uganda: Kajjansi, Gulu, Jinja, Kampala, Kayunga, Mukonno, Buikwe, Wakiso, Luweero, Mpigi, and Nakasongola

Kenya: Kirinyaga, Nairobi, and Uasi Gishu/Rift Valley

For more details on research locations, see the AquaFish Site Descriptions**.**

Project Description

2016-2018 Implementation Plan Investigations

1. Development of Captive Breeding, Larval Rearing Technologies and Management Practices for African Lungfish (*Protopterus aethiopicus*) (16IND03AU)
2. Implementing and Assessing Cell-Based Technical and Marketing Support Systems for Small- and Medium-scale Fish Farmers in Uganda (16FSV02AU)
3. Assessment of Price Volatility in the Fish Supply Chain in Uganda (16MER02AU)
4. Women in Uganda Aquaculture: Nutrition, Training, and Advancement (16HHI04AU)
5. Water, Water Quality, and Pond Bottom Soil Management in Ugandan Aquaculture (16BMA05AU)

Continuing Investigations from the 2013-2015 Implementation Plan

1. Assessment of Growth Performance of Monosex Nile Tilapia (*Oreochromis niloticus*) in Cages Using Low-Cost, Locally Produced Supplemental Feeds and Training Fish Farmers on Best Management Practices in Kenya (13SFT06AU)
2. Formulation and Manufacture of Practical Feeds for Western Kenya (13SFT07AU)
3. Development of Low-Cost Aquaponics Systems for Kenya (13BMA05AU)

Principal Project Personnel

Auburn University, US (US Project University) Joseph Molnar – US Project PI Claude Boyd – US Investigator Patricia James - Research Assistant Jeffrey Terhune – US Investigator **National Fisheries Resources Research Institute, Uganda (Lead HC Institution)** John Walakira – HC Project PI Gertrude Atukunda – HC Investigator Moureen Matuha – HC Investigator **Makerere University, Uganda** Theodora Hyuha – HC Co-PI	**University of Eldoret, Kenya** Charles Ngugi – HC Co-PI & Kenya PoC Julius Manyala – HC Investigator **University of Arizona, US** Kevin Fitzsimmons – US Co-PI **Alabama A&M University, US** James Bukenya – US Co-PI **Fisheries Training Institute, Uganda** Gertrude Abalo – HC Co-PI **North Carolina State University, US** Benjamin Reading – US Co-PI Russel Borski – US Investigator

Achievements

In FY18, research in Kenya and Uganda continued efforts focused on improving livelihoods, nutrition, and income for fishers, farmers, and vulnerable communities by working to identify and resolve bottlenecks that limit the advancement of fish culture. A study on mobile phone use by fish farmers in Uganda developed and tested eight modules accessed on three platforms (basic phones, smartphones, and on the web) for fish farmers based on previously assessed needs, including pond management, feeds, broodstock and water quality management, stocking and harvesting, and market price. After testing with several focus groups, the application has been introduced to farmers, researchers, and government officials through workshops and several tradeshows throughout Uganda.

Additional market-side research in Uganda built on previous work that examined seasonal variation in fish prices. Fish price forecasts can provide critical information to fish farmers, informing their production and marketing decisions. AquaFish IL work in Uganda, thus analyzed the seasonal price variations in the catfish subsector and developed a seasonal model for forecasting monthly farm-gate catfish prices. The model forecasts that the highest catfish prices, adjusted for seasonality appear in June, July, and August. Farmers can now use model output to develop market-specific strategies and manage production risk.

Grow-out and reproductive experiments have continued to guide the development of low-cost technologies for propagating and producing African lungfish to improve household nutrition, food security, and income. This study determined that fertilized lungfish eggs will hatch within a temperature range between 24-32°C, but optimally at 27°C, when bred in captivity. Results also indicated that larvae will start feeding on artificial diets at 18-20 days after hatch and larval growth and survival is enhanced when fed a combination of decapsulated *Artemia sp.* or live *Moina* and microdiet (35-57% Crude Protein). Through this study, the AquaFish IL has generated valuable information on lungfish feeding; and the reproductive studies will help determine the best method to spawn fish in captivity.

Research in Kenya continued to take important steps forward in demonstrating practical approaches to aquaculture using aquaponics on small- and medium-scales. A small-scale aquaponics system was designed and is now used as an educational tool for farmers in urban and/or water deficient areas. Over 200 stakeholders have viewed the small-scale system. A Medium-scale aquaponics system was also implemented, to simultaneously growing leafy greens and tilapia. On-farm trial of the medium-scale system, demonstrated potential profits increased by 50%.

Capacity Building

For FY18, capacity building efforts in Kenya and Uganda built on partnerships with farmer organizations to continue to amplify and disseminate the insights and recommendations coming from AquaFish IL research. In Uganda, AquaFish IL co-sponsored the Uganda National Aquaculture Show, 10-14 July, where the AquaFish IL team displayed information on their lungfish research and the mobile phone application. The team also joined the Uganda Women Fish Network to sell their farmed tilapia products and welcome new farmers into the network.

Twenty-four long-term students (6 women and 18 men) were supported and mentored under this project in FY18 at Makerere University in Uganda; Kenyatta University, Karatina University, and University of Eldoret in Kenya; and Auburn University in the US. These students pursued Bachelor's (13), Master's (8), and PhD (3) degrees.

Presentations and Publications

Publications

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Bukenya, J.O. 2018. Price Seasonality in the Catfish Value Chain in Uganda. Professional Agricultural Workers Journal 6(1): 13-25.

Bukenya, J. 2017. Forecasting Farm-gate Catfish Prices in Uganda Using SARIMA Model. Finance and Marketing 2(2): 1-12.

Obado, E., J. Ani, P.O. Raburu, J.O. Manyala, C.C. Ngugi, K. Fitzsimmons, and H.S. Egna. 2018. Effects of Lysine and Methionine Supplementation and Cost-effectiveness in Production of Nile Tilapia Diets in Western Kenya. 5(3): 12-23.

Rono, K., J.O. Manyala, and D. Lusega. 2018. Effect of Iron Amino Acid Chelate Supplemented Fish Feeds on Nutrients Composition of Spinach (*Spinacia oleracea)* in an Aquaponic System in Kenya. International Journal of Sciences: Basic and Applied Research 37(2): 162-172.

Rono, K., J.O. Manyala, D. Lusega, J.A. Sabwa, E. Yongo, C. Ngugi, K. Fitzsimmons, and H. Egna. 2018. Growth Performance of Spinach (*Spinacia oleracea)* on Diets Supplemented with Iron-Amino Acid Complex in an Aquaponic System in Kenya. International Journal of Research Science and Management, 5(7): 117-127.

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Hyuha, T. 2018. A Comparative Analysis of Fish Trade in Uganda: Gender Perspective. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Matuha, M., J. J. Molnar, G. Atukunda, J.K. Walakira, S. Namatovu and E. Nabafu. 2018. Design of Mobile Phone Application to Facilitate Information Sharing Among Fish Farmers in Uganda. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

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THEME C: ENVIRONMENTAL MANAGEMENT FOR SUSTAINABLE AQUATIC RESOURCES USE

Asia Project: Bangladesh

Project Title: ***Enhancing Aquaculture Production Efficiency, Sustainability, and Adaptive Measures to Climate Change Impacts in Bangladesh***

Location

Bangladesh: Bagerhat, Barisal, Khulna, Mymensingh, Patuakhali, and Satkhira

For more details on research locations, see the AquaFish Site Descriptions**.**

Project Description

2016-2018 Implementation Plan Investigations

1. Advancing Semi-intensive Polyculture of Indigenous Air-breathing Fishes, Koi and Shing, with Major Indian Carps for Enhancing Incomes and Dietary Nutrition while Reducing Environmental Impacts (16MNE01NC)
2. Nutritional Conditioning during Larval Development to Improve Feed Efficiency and Identify Beneficial Gut Flora in Tilapia (16SFT02NC)
3. Better Management Practices for *Mola*-Prawn-Carp Gher Farming Integrated with Pond Dyke Cropping for Increased Household Nutrition Earnings of Rural Farmers in Southwest Bangladesh (16HHI01NC)
4. Tilapia and Koi (climbing perch) Polyculture with *Pangasius* Catfish in Brackish (hyposaline) Waters of Southern Bangladesh (16IND02NC)
5. Dissemination of AquaFish Innovation Lab Technologies for Improving Food Production Efficiency and Livelihoods of the People of Bangladesh (16MNE02NC)

Principal Project Personnel

North Carolina State University, US (US Project University) Russell Borski – US Project PI Peter Ferket – US Investigator **Bangladesh Agricultural University, Bangladesh (Lead HC Institution)** Shahroz Mahean Haque – HC Project PI Mst. Kaniz Fatema – HC Investigator Sadika Haque – HC Investigator Md. Ashraful Islam – HC Investigator	**Khulna University, Bangladesh** Khandaker Anisul Huq – HC Co-PI **Patuakhali Science and Technology University, Bangladesh** Md. Lokman Ali – HC Co-PI Zahid Parvez Sukhan – HC Investigator **Shushilan NGO, Bangladesh** Sattyananda Biswas – HC Co-PI

Achievements

In FY18, research in Bangladesh continued testing and optimizing novel technologies and management practices for intensifying seafood production while maximizing utilization of nutrient input and reducing environmental impacts through polyculture, improving overall aquaculture production efficiency and increasing incomes of farmers in Bangladesh. Previous polyculture research demonstrated that inclusion of two major Indian carp, rohu and catla, either alone or in combination, has little impact on koi production and provides a means for farmers to enhance their income by providing additional fish (carps) for consumption or sale at local markets. Collectively, analyses indicated that: 1) koi polyculture with major Indian carps provided the opportunity to produce additional fishes while improving koi production, and 2) reductions in feed ration along with pond fertilization provided further cost savings in koi-carp polyculture without negatively impacting fish production.

In previous work AquaFish researchers demonstrated for the first time that *Pangasius* survival and growth rates in saline waters up to 12 ppt do not significantly differ from those in less saline waters. Building on this work in FY18, researchers explored the potential to add profit for fish farmers in brackish water systems by adding koi (climbing perch, *Anabas tesudineus*) and tilapia in co-culture. Results showed that monoculture of *Pangasius* had the highest fish yields, but tilapia-*Pangasius* polyculture had the highest profit because of tilapia's high market value in Bangladesh. The ability to utilize hyposaline waters for the polyculture of *Pangasius* and tilapia has potential to enhance efficiency and economic return of these systems for coastal farmers in Bangladesh.

Two studies focused more specifically on improving household nutrition, income generation, and livelihoods through better management practices in Gher farming integrated with pond dyke cropping and through nutritional conditioning for tilapia production. To increase household income, researchers sought to improve nutrient uptake and utilization along with production efficiency of tilapia culture. To do so, researchers assessed the effects of limited-term reduced protein diets for post-yolk sac Nile tilapia fry on long-term growth, intestinal gene expression, and fecal microbiome. During on-station trials in tanks, growth data indicated that tilapia fry fed reduced protein diets for 7 or 14 days may improve overall growth of fish later in life, but on-farm trials in ponds suggest that early protein restriction only enhanced adult feed conversion ratios. Limited protein early in life had little apparent effect on fish gut microbiome, but the diversity of microbes is dynamic and changes over time. Results indicated that limiting protein early in life could reduce feeding costs and enhance production if performed in clean tank systems.

Capacity Building

During FY18, work in Bangladesh focused capacity-building efforts on strengthening community, institutional, and individual partnerships and capacities. Toward this goal, the project partnered with seven host-country university faculty at three regional universities in Bangladesh, and with one senior project scientist from an NGO, Sushilan. The institutions encompass a broad geographical range within Central, South, and Southwest Bangladesh. The faculty, students, and staff gained considerable training and knowledge on management of community development projects, conduct of research trials and an improved understanding of the importance of reporting project outcomes and impacts. University undergraduate coursework and associated field laboratory experiences on water quality and pond management also benefited from the project as experimental ponds supported by AquaFish IL were used for teaching and training. The project was very successful in the education and training of the next generation of aquaculture and fisheries scientists.

During this fiscal year, 25 (12 women and 13 men) students including two Bachelor's, 17 Master's, three PhD's, and two post-doctoral fellows, and one research assistant were supported by this project. These students studied at Bangladesh Agricultural University (BAU), Patuakhali Science and Technology University, and Khulna University in Bangladesh, and North Carolina State University (NCSU) in the US. Students were trained on hypothesis driven experimental design, various research techniques, data collection and analyses, and other critical features to successfully test, carry-out and disseminate technologies for aquaculture and fisheries development.

Presentations and Publications

Publications

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Presentations

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THEME C: ENVIRONMENTAL MANAGEMENT FOR SUSTAINABLE AQUATIC RESOURCES USE

Asia Project: Nepal

Project Title: ***Development of More Efficient and Environmentally Sustainable Aquaculture Systems for Nepal***

Location

Nepal: Rampur, Chitwan, Majhui, Kawasoti, Nawalparasi, Kathar, and Terai Region

For more details on research locations, see the AquaFish Site Descriptions**.**

Project Description

2016-2018 Implementation Plan Investigations

1. A Comparison of Monoculture and Polyculture of Tilapia with Carps for Pond Production Systems in Nepal (16BMA03UM)
2. Developing New Systems for Periphyton Enhancement in Farmers' Ponds (16BMA04UM)
3. Improving Seed Production of Sahar (*Tor putitora*) in Chitwan, Nepal (16QSD02UM)
4. Outreach to Increase Efficiency of Aquaculture in Nepal (16HHI03UM)

Principal Project Personnel

University of Michigan, US (US Project University) James Diana – US Project PI **Agriculture and Forestry University, Nepal (Lead HC Institution)** Madhav Shrestha – HC Project PI Dilip Kumar Jha – HC Investigator Narayan Pandit – HC Investigator Sunila Rai – HC Investigator Kamala Gharti – HC Investigator Nabin Babu Khanal – HC Investigator	**Directorate of Fisheries Development, Nepal** Rama Nanda Mishra – HC Co-PI **Fisheries Research Center, Nepal** Jay Dev Bista – HC Co-PI **Nepal Agriculture Research Council, Nepal** Suresh Kumar Wagle – HC Co-PI

Achievements

In FY18, AquaFish IL focused on polyculture, household nutrition, enhanced production of native species, and contributing to technology development and capacity building for aquaculture in Nepal. Successful work resulted in improved seed production methodologies for sahar, an economically important native fish. Building on breeding experiments conducted in earlier studies, in which female sahar responded to hormonal injection and successfully released eggs, FY18 research further evaluated sahar fry growth and survival at different stocking densities. Results showed that survival was not affected by stocking density and higher densities correlated with higher growth rates. Also completed in FY18, experiments in Nepal evaluated polyculture systems with tilapia, carps, and sahar in comparison with monoculture tilapia. Results of on-station and on-farm trials showed that the addition of Nile tilapia and sahar had no adverse effects on growth and production of all carp species, or in pond water quality. It was concluded that the carp-tilapia-sahar polyculture, carps and monosex tilapia polyculture, and monosex tilapia culture with fertilization and feeding systems were equivalent practices and better than the presently used carp polyculture system to enhance pond productivity, species diversification and economically viable aquaculture.

To increase the growth of periphyton in ponds and, therefore reduce the need for feed, on-farm experiments tested the utility of four substrates recommended by farmers at workshops: split bamboo

mats, whole bamboo, plastic bottles, and the midrib of banana leaves. On-farm trials were conducted with 15 women farmers from a women's cooperative in Majhui and 15 farmers (12 men and three women) from a cooperative in Seri, but heavy floods completely inundated ponds in one region (Chitwan) causing highly variable data in that region. In the region with less flood damage (Nawalparasi), feed conversion ratio was significantly lower in ponds with split bamboo than the control. In Nawalparasi, fish production, gross margins, and gross returns for the treatments with substrates were higher than the controls without substrate. This study could help small-scale fish farmers increase fish production, while decreasing their production costs.

In FY18 work with school ponds in Nepal resulted in further success, expanding to two more secondary schools in Nawalparasi and Chitwan (four schools in total). At the two schools with new ponds, tests were administered for the 86 participating students to measure student knowledge on aquaculture and the nutritional benefits of fish before and after training. Overall, students showed improvements in test scores after participating in the year-long training. In addition to the establishment of the ponds and the aquaculture curriculum at the elementary schools, researchers also established two women's groups to further integrate fish farming into the community and to help ensure the long-term sustainability of the school ponds program.

Capacity Building

In FY18, AquaFish IL work in Nepal continued to strengthen human and institutional capacity through trainings and collaborations. AquaFish IL researchers hosted nine workshops and training events to evaluate different types and importance of substrates for the production of periphyton in aquaculture, the importance of aquaculture to household nutrition, and improvements in polyculture systems. During this fiscal year, researchers interacted with 295 farmers and students, of which, 60% (178) were women and girls. In formal long-term training programs, US and Nepalese AquaFish IL partners mentored 63 degree-seeking students in pursuit of Bachelor's (51), Master's (11), and PhD (1) degrees. These students were enrolled at Agriculture and Forestry University (AFU) in Nepal. Twenty nine of these students (46%) were women and 34 were men (54%).

With AquaFish IL support and partnership over many years, AFU has developed innovative aquaculture and fisheries curricula, programs, and courses to further enhance AFU's reputation in Nepal as a leading research institution. In FY18, AquaFish IL partners at AFU continued to expand and improve resources for its aquaculture program, including those that support teaching, experimentation, and hatchery activities.

Presentations and Publications

Publications

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Presentations

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Shrestha, M.K. J.S. Diana, and H.S. Egna. 2018. Tilapia Aquaculture in Nepal: History from Introductions to Farmers Ponds. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

THEME D: ENHANCED TRADE OPPORTUNITIES FOR GLOBAL FISHERY MARKETS

Asia Project: Cambodia & Vietnam

Project Title: ***Improving Food Security, Household Nutrition, and Trade through Sustainable Aquaculture and Aquatic Resource Management in Cambodia and Vietnam***

Location

Cambodia: Kandal province, Kampong Chnang province, Kampong Thom province, Siem Reap province, Phnom Penh, Prey Veng province, Tonle Sap region, Kampong Cham province, Preah Sihanouk province, Battambang province, Pursat province, Kandal province, and Kratie province

Vietnam: An Giang province, Dong Thap Province, Can Tho province, Hau Giang, Camau, Longan, Vinh Long, and Tra Vinh province

For more details on research locations, see the AquaFish Site Descriptions**.**

Project Description

2016-2018 Implementation Plan Investigations

1. Genetic Diversity of Striped Snakehead (*Channa striata*) in Cambodia and Vietnam (16QSD01UC)
2. Guidance and Policy Recommendations for Sustainable Snakehead Aquaculture and Aquatic Resource Management in Cambodia and Vietnam (16PDV01UC)
3. Sustainable Snakehead Aquaculture in Cambodia (16IND01UC)
4. Pellet Feed Improvements through Vitamin C Supplementation for Snakehead Culture (16SFT01UC)
5. Enhancing Food Safety and Household Nutrition of Women and Children through Aquaculture and Capture Fisheries in Cambodia and Vietnam in the Dry Season (16FSV01UC)

Principal Project Personnel

University of Connecticut, US (US Project University) Robert Pomeroy – US Project PI Sylvain DeGuise – US Investigator Marta Gomez-Chiarri – US Investigator **Inland Fisheries Research and Development Institute, Cambodia (Lead HC Institution)** Nam So – HC Project PI Phanna Nen – HC Investigator Navy Hap – HC Investigator Bunthang Touch – HC Investigator Phen Chheng – HC Investigator	**University of Rhode Island, US** David Bengtson – US Co-PI **Can Tho University, Vietnam** Tran Thi Thanh Hien – HC Co-PI & Vietnam PoC Tran Ngoc Hai – HC Investigator Truong Hoang Minh – HC Investigator Pham Minh Duc – HC Investigator Duong Thuy Yen – HC Investigator

Achievements

In FY18, this project completed research in Cambodia and Vietnam to support the development of sustainable snakehead aquaculture, inform climate change adaptation strategies for fish farming, and evaluate fish consumption and nutrition. Leading up to work conducted in FY18, a major accomplishment in Cambodia was the lifting of the snakehead culture ban in April 2016, resulting in part from AquaFish IL research and policy development on sustainable snakehead aquaculture practices. With the ban newly lifted, work to evaluate impacts and to continue the development of sustainable practices was completed. One AquaFish IL investigation showed that both Vietnamese hatchery snakehead (domesticated) and Cambodian indigenous wild snakehead (non-domesticated) accepted formulated pelleted feed (rather than

small-sized fish); however, on pelleted feed, offspring of domesticated broodstock of Vietnam origin grew more than twice as fast as offspring from wild Cambodian broodstock. Fish from this study were retained and raised as future broodstock in support of continued efforts to domesticate Cambodian snakehead. Although snakehead can accepted pelleted feed, anecdotal reports from farmers suggested fish fed these diets suffer from lordosis and scoliosis, issues associated with ascorbic acid (vitamin C) deficiency. Through on-station and on-farm trials, the AquaFish IL determined that diets supplemented with 500 mg of ascorbic acid per kg of feed resulted in the highest survival rate, highest yield of fish, best feed conversion ratio, and the highest profit margin.

To further increase the sustainability of snakehead aquaculture, one study characterized and compared the genetic diversity of domesticated and non-domesticated strains of snakehead in Vietnam and Cambodia. Sequence data of two mitochondrial markers (Cytochrome b and D-loop region) revealed that the highest level of genetic diversity was found in wild snakehead populations in Cambodia, and the lowest was in Vietnamese domesticated populations. There were no significant genetic differences among domesticated populations, but collectively domesticated populations were significantly different from wild populations. The low genetic diversity of hatchery populations in Vietnam indicated an urgent need for genetic improvement programs to prevent inbreeding depression.

To help improve household food security, particularly for women and children, work was conducted to analyze the nutrient density of commonly consumed fish and other aquatic animals from both capture fisheries and aquaculture. Data illustrated a wide diversity in nutrient composition of fish species and that small species in particular are rich in nutrient components, which could be promoted to decrease malnutrition in the region.

Capacity Building

FY16 saw the lifting of a more than 10-year long ban on snakehead farming in Cambodia. In FY18, AquaFish IL researchers continued developing sustainable snakehead feed and focused on ecologically-friendly rearing methods. Both lines of research have helped enable ecologically and economically sustainable culture of snakehead in Cambodia. This research increased the capacity of fish farmers in Cambodia, a country where the majority of the population relies on aquatic resources for income and nutrition.

In Cambodia and Vietnam, researchers continue to build capacity through support of students. This project supported the education of 13 long-term students at all degree levels in FY18; 77% (10) of these were women. These students studied at Can Tho University (CTU) and Nha Trang University in Vietnam, and Inland Fisheries Research and Development Institute (IFReDI) and Royal University of Agriculture in Cambodia.

Presentations and Publications

Publications

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Hien, T.T.T., PM. Duc, N.V. Khanh, T.T.T. Hoa, T.M. Phu and D.A. Bengtson. 2018. Pellet Feed Improvements Through Vitamin C Supplementation for Snakehead Fish *Channa striata* Culture in Vietnam. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Hien, T.T.T., T.L.C. Tu, T.M. Phu, P.M. Duc, B.M. Tam, H.V. Hien, P. Chheng, P. Nen, N. So, R. Pomeroy, H. Egna, and D.A. Bengtson. 2018. Developing Pellet Feeds for Snakehead *Channa striata* Culture in Vietnam and Cambodia. [Poster Presentation]. AQUA 2018, Montpellier, France, 25-29 August 2018.

Hoa, N.P., V.P. Tung, N.V. Bao, N.V. Tu. 2018. Investigating the Effects of Different Feed and Probiotics on the Survival and Growth of Goby (*Oxyeleotris marmorata* Bleeker 1852) 3-45 Days Old. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Nen, P., P. Chheng, N. So, T.T.T Hien, B.M. Tam, H.S. Egna, and D.A. Bengtson. 2018. Performance of Domesticated (Vietnamese) vs. Non-domesticated (Cambodian) Snakehead *Channa striata* During Weaning and Grow-out. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Nen, P., P. Chheng, N. So, T.T.T Hien, B.M. Tam, H.S. Egna, and D.A. Bengtson. 2018. Performance of Domesticated (Vietnamese) vs. Non-domesticated (Cambodian) Snakehead *Channa striata* During Weaning and Grow-out. [Oral Presentation]. International Sustainable Agricultural Intensification and Nutrition, Phnom Penh, Cambodia, 10-13 January 2018.

Tam, B.M., T.T.T. Hien, P.M. Duc, P.T. Liem, N.H.Q. Thang, and N.V. Khanh. 2018. Seed Production and Culture of Snakehead *Channa striata*, in the Mekong Delta Vietnam. [Poster Presentation]. AQUA 2018, Montpellier, France, 25-29 August 2018.

Touch, B., C.V.C. Barba, M.G. Yee, E.I. Dizon, N. So, P. Chheng, R.S. Pomeroy, H.S. Egna, and W.A. Hurtada. 2018. Effect of Consumption of Complementary Traditional Food on the Growth and Iron Status of 6 to 15 months Old Cambodian Children in Prey Veng Province Cambodia. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.

Uy, S., D.T. Yen, P. Chheng, N. So, T.T.T. Hien, R. Pomeroy, and H. Egna. 2018. Sustainable Use of Snakehead Genetic Resources for Aquaculture in Cambodia: Recommendations from Genetic Data. [Poster Presentation]. AQUA 2018, Montpellier, France, 25-29 August 2018.

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LESSONS LEARNED

The lessons learned highlighted below are a compilation of FY18 experiences.

- **Strategic investment creates a self-sustaining professional network with lasting host country benefits.** Fostering connections with individuals and institutions around the world was a primary component of the AquaFish IL HICD efforts. These networks helped create long-lasting collaborations and provided both trainees and organizations with resources that they can access and build upon throughout their careers. A self-sustaining network of international aquaculture professionals who are in positions to support and collaborate with each other, and to drive the research and capacity building agenda forward, was built over many years through strategic efforts and strong leadership by the Director and PI, Dr. Egna. Its sustainability was prioritized in the final program years through efforts such as developing and monitoring exit strategies to enable host country partners to be self-sustaining and initiate new lines of research once the program ends, through supporting regional initiatives, and importantly, by connecting host country partners with potential government and industry stakeholders.

  Many recent examples of network successes were observed in FY18. A prime example of career advancement facilitated by involvement in the AquaFish IL network is Dr. Steve Amisah's recent appointment by the President of Ghana as a Member of the Board of the Fisheries Commission of Ghana in accordance with the Fisheries Act of 2002, Act 625. This appointment came in March 2018, just six months after Dr. Amisah's appointment as Provost of the College of Agriculture and Natural Resources at KNUST. Host country partners now directly reach out to and support each other, for example, Dr. Sunila Rai, a host country investigator from AFU in Nepal recently (June 2018) attended a forum on Fisheries Education at Shanghai Ocean University at the invitation of Dr. Liping Liu, an AquaFish IL external advisory member. Additionally, AquaFish IL partners from Tanzania, Kenya, and Uganda formed a regional network, the Aquaculture Network of East Africa (ANEA) with colleagues from the East African Economic Zone, to share knowledge and transfer technologies within the region. Dr. Hien, an AquaFish partner at Can Tho University (CTU) in Vietnam, offered full scholarships to five former AquaFish-supported students from Bangladesh, Nepal, and Uganda, to continue their aquaculture studies at CTU, further fostering the AquaFish IL network across continents.

- **USAID Innovation Labs must be nimble and resourceful to succeed during times of uncertainty.** AquaFish IL research projects experienced significant delays due to natural disasters and political events in the final project year, a time when such challenges are difficult to overcome. Through conscientious project management and thoughtful planning, AquaFish IL projects in Africa and Asia were largely able to adapt to many of these challenges by delaying harvest, finding alternative sources of water to respond to irrigation issues, and on-the-ground ingenuity of well-trained researchers and participants. Although projects adapted and worked diligently to complete the proposed research, the refinement and transfer of findings and technologies would have suffered in many cases without additional time. As such, the AquaFish IL ME (OSU) submitted an official request for a one-year no-cost extension (NCE) to USAID in October 2017, six months prior to the scheduled program end date of 29 March 2018. The AquaFish IL proceeded to operate under a period of uncertainty for four months before receiving approval notification from USAID in February 2018 to extend the award for 6 months (through 28 September 2018). This period of ambiguity made prioritizing research, capacity building, and closeout efforts extremely challenging for the AquaFish ME and its US and HC subcontractors alike. Fortunately, AFIL is a nimble and resourceful program, and with the additional time that was eventually granted and for which AFIL is very grateful, results and technologies were disseminated to an even wider range of stakeholders, including through publication in scientific literature and partnerships with market linkages. The time extension also

enabled the AquaFish IL ME to adapt its initial closedown approach, whereby all subcontracting partners were scheduled to end at the same time (28 February 2018), to a phased closedown, in which projects that experienced the greatest delays were given a later end date than projects that were able to stay closer to schedule. This phased approach was beneficial to subcontracting partners by allowing them to comprehensively wrap up their research and outreach efforts; and the staggered closedown enabled the ME to more systematically review and process technical and fiscal deliverables. The ME appreciates AOR Dr. Shivaun Leonard and USAID contracts office for the NCE and for working with AFIL towards a seamless closedown.

- **Assessing feasibility and building partnerships through exploratory studies when initiating work in a new country.** In FY18, the AquaFish IL carried out two US-based desk studies focused on Burma. One study evaluated the contribution of fish to household diets and nutrition in Burma and the other focused on the potential impacts of climate change to Burmese fish production. Before initiating these studies, the AquaFish IL anticipated that there may be challenges in acquiring the necessary data. To address this, connections were established with Michigan State University and various colleagues in Burma. Through them, enough data for were obtained to complete this work and establish the groundwork for future research on the aquatic resources in Burma. Further, these exploratory studies established an emerging network of researchers and institutions for the development of new in-country collaborations. The results from these studies represent a first step toward highlighting the contributions of fish to Burmese human health, the impacts of climate change on Burmese fish production, and potential management actions to mitigate threats to fish production. Additionally, this work built on and strengthened existing connections with Burmese colleagues, showing promise for future collaborations to further explore these research areas.

- **Expanding communications and information sharing through regional coordinators.** At program inception, the AquaFish IL Director established Regional Centers of Excellence (RCEs) for three major regions: Africa, Asia, and Latin America and the Caribbean (LAC). For each RCE, regional coordinators were identified to enhance communications with beneficiaries and stakeholders within their region. RCE coordinators were selected for their aquaculture expertise and, importantly, for their connectedness and integration in the aquaculture community in their respective regions. They were given access to information and technologies and provided resources to participate in regional and international meetings and conferences. This RCE model, which was been in place for over a decade, succeeded in expanding the reach of AquaFish IL research outputs within and between regions. Further, RCE coordinators are well-positioned to continue to facilitate the transfer of aquaculture best management practices, advise on regional research efforts, and build collaborative networks into the future.

  The AquaFish RCE Coordinators for Africa, based in Ghana and Kenya, were able to help overcome the region's vastness and restricted road infrastructure by utilizing their existing networks to improve communications with end-users of AquaFish IL research outputs. They also continue to play an important role in establishing the World Aquaculture Society Africa Chapter. In Latin America, the AquaFish IL LAC RCE coordinators, based in Brazil and Mexico, strengthened communications by utilizing existing networks. They broadened AquaFish IL's reach to Belize, Bolivia, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Peru. They also leveraged AquaFish IL support to propose a new strategy to form an electronic discussion forum on sustainable aquaculture in Latin America and to disseminate information in AquaNoticias, the bulletin of the LACC/WAS (Latin-American and Caribbean Chapter of the World Aquaculture Society). The RCE coordinator for southeast Asia continued to help develop trainings focused on developing culture-based fisheries in Cambodia, as well as assisting with the development and translation of guidebooks in English to local languages to promote information dissemination to small-scale aquaculture farmers.

VI. HUMAN AND INSTITUTIONAL CAPACITY DEVELOPMENT

HUMAN CAPACITY DEVELOPMENT

AquaFish Innovation Lab capacity-building efforts benefit stakeholders in Host Countries and the US, and regionally through the transfer of knowledge and technology. The AquaFish IL supports trainees in both short- and long-term trainings and provides opportunities for early-career scientists, farmers, and other stakeholders to make connections and strengthen networks. Further, the AquaFish IL understands that women's participation is essential to the successful growth and development of the aquaculture and fisheries sectors. To ensure that women are included in the development agenda in meaningful and equitable ways, the AquaFish IL has set benchmarks to track the inclusion of women and men in projects funded by the AquaFish IL. Some key capacity building strategies include: collecting and analyzing disaggregated gender data from individual research and outreach projects, tailoring specific extension and technical services to women, gender mainstreaming throughout all aspects of the research and development enterprise, engaging outreach specialists who are sensitive to challenges facing underrepresented groups, and setting a 50% benchmark for women's participation in short- and long-term trainings.

Each of the six AquaFish IL projects is designed to address country-specific development gaps. The overall capacity building effort is one of the cross-cutting elements of the program and is a fundamental component towards addressing the AquaFish IL mission.

Short-Term Training

During FY18, a total of 22 short-term trainings took place in four AquaFish IL Host Countries in Africa and Asia, reaching 786 trainees. Women represented 44% of trainees (Table 1).

Table 1. AquaFish IL short-term trainings, the country in which the trainings were held, and the number of trainees (gender data for participants provided where available).

Brief Purpose of Training	Country	Number of Trainees		
		Total	Women	Men
Integration of Nutrient-rich fish SIS and vegetables with Prawn-Carp Gher farming in Southwest Bangladesh	Bangladesh	24	12	12
Polyculture of Air breathing Fishes, Koi and Shing with Indian Major Carps for Enhancing Income and Dietary Nutrition while Reducing Environmental Impacts	Bangladesh	79	8	71
Dissemination of Aquafish Innovation Lab Findings: Reduced feeding strategies and/or polyculture	Bangladesh	63	16	47
Training on Pangasius culture in brackish water	Bangladesh	50	17	33
Training on Pangasius culture in brackish water	Bangladesh	50	20	30
Integration of Nutrient-rich fish SIS and vegetables with Prawn-Carp Gher farming in Southwest Bangladesh	Bangladesh	54	9	45

Integration of Nutrient-rich fish SIS and vegetables with Prawn-Carp Gher farming in Southwest Bangladesh	Bangladesh	25	14	11
Integration of Nutrient-rich fish SIS and vegetables with Prawn-Carp Gher farming in Southwest Bangladesh	Bangladesh	25	18	7
Integration of Nutrient-rich fish SIS and vegetables with Prawn-Carp Gher farming in Southwest Bangladesh	Bangladesh	25	18	7
Demonstration trial in a private farm in Chitwan on the new production system	Nepal	9	4	5
Workshop on disseminating results from polyculture project	Nepal	28	28	0
On-farm trials for periphyton experiments	Nepal	30	18	12
Workshop for non-adopting farmers	Nepal	43	27	16
Workshop for extension personnel	Nepal	60	22	38
Workshop with fish hatchery farmers, commercial fish farmers, government scientists and extension officers*	Nepal	-	-	-
Training at school 1 on pond construction and farming	Nepal	39	23	16
Training at school 2 on pond construction and farming	Nepal	43	19	24
Training for women's group 1 on aquaculture and its role in household nutrition	Nepal	20	16	4
Training for women's group 2 on aquaculture and its role in household nutrition	Nepal	23	21	2
Training on value chains and marketing in aquaculture for farmers	Uganda	26	18	8
Workshop to train fish farmers & Village Extension Officers on water quality management- Improved Fish Farming And Best Management Practices At Institute Of Continuing Education (ICE), Sokoine University Of Agriculture (SUA)	Tanzania	28	6	22
Workshop to train fish farmers on feed formulations and best feeding strategies/diets- On Improved Fish Farming And Best Management Practices At Mbeya Municipal Council, Tanzania	Tanzania	23	6	17
Improved Fish Farming And Best Management Practices At Fisheries Education And Training Agency (FETA), Nyegezi Campus, Mwanza	Tanzania	19	7	12

*These workshops were held in conjunction with another AquaFish IL-supported workshop. They are counted as separate events, but participants were not double counted.

Long-Term Trainings

Building human and institutional capacity in partner countries is a hallmark of the AquaFish IL collaborative research program. The AquaFish IL provides financial support, research mentoring, and academic guidance for students in undergraduate and graduate programs in a wide array of disciplines including aquaculture, fisheries, aquatic ecology, economics, and engineering. Long-term degree students constitute a pipeline of educated professionals who are positioned to move on to careers in government, academia, and private enterprise upon graduation.

In FY18, the AquaFish IL partners in nine countries supported and mentored 151 long-term students at 19 different institutions, with a program-wide total of 73 (48%) women and 78 (52%) men.

The degree breakdown for long-term trainees in FY18 is as follows: 81 (54%) in a Bachelor's program; 55 (36%) in a Master's program; 13 (9%) in a PhD program; and two post-doctoral fellows.

INSTITUTIONAL DEVELOPMENT

Since 2006, the AquaFish Innovation Lab has helped HC institutions develop specialized curricula and institutional proficiency for building local capacity. The AquaFish IL is expanding capacity in our Host Countries by collaborating with faculty and researchers, supporting degree-seeking students, developing aquaculture-related curriculum, and building partnerships with local aquaculture and fisheries organizations. In FY18, AquaFish IL partners from the Inland Fisheries Research and Development Institute (IFReDI) in Cambodia and Can Tho University (CTU) in Vietnam attended the first ever International Sustainable Agricultural Intensification and Nutrition conference in Cambodia. In addition to presenting their research at the conference, these partners built connections with new scientists and agriculturists who are also developing technologies that improve food security and agriculture efficiency. This type of networking is essential in the final year of the AquaFish IL in order to promote the longevity of the AquaFish IL mission.

CTU has also developed new aquaculture curricula and has offered full scholarships to five former AquaFish-supported students from Bangladesh, Nepal, and Uganda, further fostering the AquaFish IL network across continents. With the help of AquaFish IL support, Yangon University (UY) in Burma is establishing a new undergraduate degree program in Fisheries and Aquaculture. This will be the first of its kind at a Burmese institution, where aquaculture and fisheries science courses have been extremely limited. Future plans include establishment of a Master's in Aquaculture, as well the development of lecture and laboratory facilities at UY.

Partners

Fostering connections with institutions around the world is a primary component of the AquaFish IL's HICD efforts. These networks help create long-lasting collaborations and provide both trainees and organizations with resources that they can access and build upon throughout their careers. The following is a list of universities where the AquaFish IL supported long-term trainees were enrolled in FY18 (for a complete list of AquaFish IL institutional affiliations, see *List of Program Partners*).

Bangladesh Bangladesh Agricultural University Khulna University Patuakhali Science and Technology University **Cambodia** Inland Fisheries Research and Development Institute Royal University of Agriculture **Ghana** Kwame Nkrumah University of Science and Technology **Kenya** Karatina University Kenyatta University University of Eldoret	**Nepal** Agriculture and Forestry University **Tanzania** Sokoine University of Agriculture **Uganda** Makerere University **US** Auburn University Michigan State University North Carolina State University Oregon State University Virginia Tech **Vietnam** Can Tho University Nha Trang University

VII. INNOVATION TRANSFER AND SCALING PARTNERSHIPS

In FY18, the AquaFish IL continuously built on lessons learned from previous experiences to make significant global and regional technological advances. Collaborative research remained focused on improving sustainable aquaculture production through the development and transfer of innovative technologies and management practices that address human health and nutrition, food security, environmental impacts, and market development.

An underlying theme of the AquaFish IL in FY18 continued to be the development of responsible aquaculture technologies and systems through a forward-thinking approach for the implementation of sustainable practices. AquaFish focused on research that creates a multiplier effect for farm-level income and worked with partners to scale up technologies for broader impacts. Supporting and partnering with HC research institutions allowed AquaFish IL researchers to customize technologies to local conditions and on-the-ground needs as part of this effort to create sustained impacts and effective technology transfer. These linkages play a critical role in the scaling process by increasing local buy-in, forging connections with other projects, and growing enabling environments. Additionally, the AquaFish IL training efforts focused on diverse stakeholders as a way to develop and build human capacity. AquaFish IL focused small- and medium-scale producers, prioritizing the development and transfer of low-cost technologies and best management practices. Efforts to increase access to inputs were coupled with trainings on innovative strategies for business management and trainings to help ensure food safety and environmental sustainability. AquaFish IL aimed to give women equal access to affordable inputs and improved technologies through training opportunities and by emphasizing equitable participation in aquaculture development in Program goals.

The tables below list the AquaFish-supported new and continuing scalable technologies in various stages of development in FY18.

Asia Project: Bangladesh

Project Partners and Collaborators

North Carolina State University (US Project University); Bangladesh Agricultural University (Lead HC Institution); Khulna University; Shushilan NGO; and Patuakhali Science and Technology University.

Technology	Description	Key Impact
Tilapia, Koi, *Pangasius* polyculture in brackish water	Koi, tilapia, and *Pangasius* can all be grown in hyposaline waters with little impact on growth. Expanding on this technology, researchers incorporated tilapia and Koi in brackish water polyculture with *Pangasius*. Both tilapia and Koi command higher prices with the market value of Koi exceeding *Pangasius* by roughly 3 times, so their incorporation into *Pangasius* culture may prove more beneficial for enhancing income while also providing a more diverse	Farmers can polyculture higher value Koi and/or tilapia with *Pangasius* catfish making more productive use of waters facing increases in salinity from sea level rise. In this study, Koi proved to be an acceptable candidate for polyculture in brackish waters (6ppt) with *Pangasius*, yielding a greater profit margin than *Pangasius* monoculture, however, antagonistic effects were observed when the two species were co-cultured together with tilapia. The

Technology	Description	Key Impact
	crop of fishes for consumption and sale.	adoption of *Pangasius* polycultures with tilapia or Koi could increase household food availability and earnings for farmers inhabiting areas affected by salinity encroachment in Southern Bangladesh.
Semi-intensive polyculture with air-breathing fish species and carp in Bangladesh	Evaluated culture of Koi (climbing perch), an air-breathing fish, with carps and found that there is no impact on Koi growth, and may actually improve it. The new polyculture technology could increase fish yields, compared with Koi monoculture alone, increasing the diversity of fish produced for income generation.	Koi is predominantly grown in monoculture, but its culture with major Indian carps allows farmers to produce more fish for consumption and sale.
Reduced feeding strategies for semi-intensive polyculture of koi and carp	Exploration of feed reduction strategies for Koi-carp Polyculture. Results showed that reducing feed inputs by 50% has no negative impacts on polyculture production of Koi or carps, providing considerable cost savings to farmers.	Exploring feed reductions further, current studies evaluated the effect of different densities of Shing stocked with Koi and carp. With fertilization to enhance nature food productions, results indicate that farmers can produce Koi and major Indian carps with 50% less feed providing considerable cost savings to farmers.
Nutritional conditioning during larval development to improve production and feed efficiency in tilapia	Evaluated the reduction of protein in the diet of post yolk-sac tilapia fry for 14 days can enhance growth of tilapia later in life. Conditioning tilapia early in life with a low protein diet may improve their capacity to utilize protein and improve growth during subsequent growout. This could enhance the efficiency of tilapia production.	During on-station trials in tanks, growth data indicated that tilapia fry fed reduced protein diets for 7 or 14 days may improve overall growth of fish later in life, but on-farm trails in ponds suggest that early protein restriction only enhanced feed conversion ratios. These results indicate that limiting protein early in life could reduce feeding costs and enhance production if performed in clean tank systems.
Fertilizers for improved polyculture of prawn-Mola-carp in gher (rice)-pond systems	Evaluated if the combination of organic (molasses and yeast) and inorganic (urea and phosphate) fertilizers enhances Prawn, mola, and carp in gher-pond polyculture. Farmers can increase production of Mola, prawn, and carps for home consumption or for domestic or export markets by utilizing a combination of organic and inorganic fertilizers. This could enhance income and nutrition of farmer household members and livelihoods.	Results have shown that the application of fertilizer in traditional gher farming system can contribute to increases fish production. Molasses/yeast with chemical fertilizer can be applied for best production. This could thus enhance economic returns for farming Mola-prawn-carp in gher/pond polyculture systems.
Improved management of vegetable cropping on aquaculture pond dykes	Farmers can readily utilize muds from their aquaculture ponds to grow tomatoes, with mud, mulch and inorganic fertilizers enhancing plant growth and fruit yield. This could allow for greater vegetable production to increase household nutrition.	Results confirm that pond muds possess excellent nutritional content that can promote better summer and winter vegetable production than dyke soils alone. In most recent studies the yield of tomato and okra on pond dyke plots was highest when soils were composed of 100% pond mud supplemented with inorganic fertilizer and mulching.

Technology	Description	Key Impact
Koi (climbing perch) culture in brackish waters	Koi (*Anabas testudineus*) is a high value fish and has grown in popularity in recent years for is good growth, wide acceptance, and appealing taste. As an air-breathing fish, Koi is hardy and can be grown in coastal regions where water bodies and ponds are faced with increased salinization from sea level rise. Optimizing koi growth in brackish waters will provide fish farmers in coastal regions the potential to culture Koi to market size in saline waters.	Koi were raised to market size in ponds with a salinity of 6ppt. Farmers have the opportunity to make more productive use of encroached hyposaline waters in the coastal southern region of Bangladesh.

Asia Project: Cambodia & Vietnam

Project Partners and Collaborators

University of Connecticut-Avery Point (US Project University); University of Rhode Island; Inland Fisheries Research and Development Institute (IFReDI, Lead HC Institution); Can Tho University; Mekong River Commission; Cambodia HARVEST Project; Cambodia Ministry of Agriculture, Forestry, and Fisheries; Kampong Cham National School of Agriculture; Royal University of Law and Economics; Royal University of Agriculture; Department of Aquaculture Development; WorldFish Center, Cambodia; and Fisheries Administration in Cambodia.

Technology	Description	Key Impact
Sustainable snakehead breeding, weaning, and rearing in Cambodia	Development and transfer of successful domestication, breeding, weaning, and rearing/growout practices for snakehead in Cambodia. This technology has helped to lift the 2005 ban on snakehead farming, helping to support the large population of snakehead fish farmers in the region.	The Cambodian government banned snakehead aquaculture in 2004 due to unsustainable methods. Recent research in Vietnam led to sustainable practices there. As part of technology transfer to Cambodia, this study was conducted to compare survival and growth of domesticated snakehead from Vietnam with those of non-domesticated snakehead from Cambodia to enhance the sustainability of snakehead farming in both countries.
Snakehead pellet feed improvements through vitamin C supplementation	The development of this technology works to provide cost-effective feeds for snakehead aquaculture in Vietnam and Cambodia, specifically by: (i) determining optimal vitamin C requirement in practical diets in laboratory and pond trials (Vietnam); and (ii) to evaluate cost-effectiveness of pellet diets with optimal vitamin C for hapa growout (Cambodia).	Dietary Vitamin C supplementation for snakehead is able to improve growth performance, immune responses, and survival of snakehead fish against *A. hydrophila* infection. Optimal results were obtained with soybean meal-based diets supplemented with 500 mg.kg-1 vitamin C supplement, in terms of survival, yield, FCR, production cost and profit. The result was also confirmed via on-farm trial in Cambodia.
Domestic snakehead genetic resource	This work seeks to characterize and compare genetic diversity of (1) wild (non-domesticated) snakehead populations collected from different natural water bodies in Cambodia, and (2) Cambodia wild (non-domesticated) striped snakehead and Vietnamese domesticated striped snakehead (*Channa striata*) collected from different hatcheries in the Mekong Delta inferred from mitochondrial DNA markers.	Findings on the genetic diversity of striped snakehead in the Mekong basin revealed important implications for breeding and broodstock selection of striped snakehead in Cambodia, where domestication of this species has just been started. Wild snakehead populations in the Tonle Sap can be good sources for breeding and domestication programs.

Asia Project: Nepal

Project Partners and Collaborators

University of Michigan (US Project University); Agricultural and Forestry University (Lead HC Institution); Nepal Agricultural Research Center; Directorate of Fisheries Development; Rural Integrated Development Society in Nepal; Shree Chadeswory Secondary School; Annapurna Higher Secondary School; Center for Aquaculture Research and Production; Sundardeep Women Fish Farmer's Cooperative; and the Mishrit Cooperative.

Technology	Description	Key Impact
Sahar fry production	This technology developed and refined protocols for the use of hormone induction to mature and breed sahar in captivity, opening up the possibility of rearing sahar on a commercial scale for restocking of natural waters and for culture in ponds.	More than 6,000 sahar fry were produced in Rampur as a result of both natural and hormone-induced spawning. Data and results from this study were transferred to commerical producers, which offers the potential for sahar fry availability for food and restocking natural populations.
Carp-Sahar-tilapia polyculture	This project determined whether or not Sahar (*Tor putitora*) and Nile tilapia (*Oreochromis niloticus*) cultured with carps increases fish production compared to existing carp polyculture systems. Carp production increased when the two species were added. Tilapia production has improved by 30%. This is a positive impact on smallholder farmers in Nepal and region. Two trials were conducted to compare the value of Nile tilapia and sahar in polyculture ponds and a culture system with only monosex tilapia.	Tilapia are widely cultured and can add economic growth to Nepal's aquaculture industry. Research results indicate that the carp-tilapia-sahar polyculture, carps and monosex tilapia polyculture, and monosex tilapia culture with fertilization and feeding systems are equivalent practices and better than the presently used carp polyculture system to enhance pond productivity, species diversification and the economic viability of aquaculture in Nepal.
Expansion of school ponds and aquaculture curriculum in Nepal	This work established ponds and an associated curriculum at 6 schools in Nepal for training of students, teachers, and adult women in aquaculture and fish consumption. The school pond program trained more than 200 students and teachers in fish farming practices, including pond construction, species selection, water quality, fish growout, fish harvest, and the nutritional benefits of eating fish. The students were able to achieve comparable fish growth statistics to local commercial farms.	Students have learned new ideas about aquaculture and fish consumption, which they can apply to their daily lives and carry with them through adulthood. Women in the same households have also learned more about using fish for additional nutrition for their families. The curriculums established at the six school offer the potential to reach many more students and households.
New systems for periphyton enhancement in fish ponds	The development of this technology tests new ways to enhance periphyton growth in ponds for natural food production for fish. Previous studies showed that bamboo mats worked very well for fish growth but were hard to manage in the pond culture system so alternative substrate materials were evaluated.	Periphyton growth is consumed by fish, which can allow reduction in feed applications to polyculture ponds without significantly impacting production of fish for consumption and sale. Results indicate that periphyton abundance and biomass did not differ significantly among four substrates tested. Comparatively, whole bamboo, split bamboo and plastic bottles are more durable. Based on fish production, profit, and availability, plastic bottles appear to be a reasonable alternative to split bamboo mats for periphyton substrate.

Africa Project: Ghana & Tanzania

Project Partners and Collaborators

Purdue University (US Project University); University of Arkansas at Pine Bluff; Virginia Polytechnic Institute and State University; University of Hawaii-Hilo; Farmerline; Kwame Nkrumah University of Science and Technology (KNUST, Lead HC Institution); Sokoine University of Agriculture; Western Indian Ocean Marine Sciences Association (WIOMSA); University of Dar es Salaam; Ministry of Fisheries and Aquaculture Development; and Pilot Aquaculture Center.

Technology	Description	Key Impact
Invertebrates as a protein source in fish feeds in Tanzania	Small-scale fish farmers in Tanzania typically cannot afford the price of fishmeal and soybean meal as protein sources in their fish diets. This study was conducted to determine the appropriate levels of substituting fishmeal and soybean meal with a combination of Moringa leaf meal and housefly maggot meal as sources of protein for Nile tilapia diets. The study aimed at determining the most suitable substrate for production of housefly (*Musca domestica*) maggots among five substrates (cow dung, chicken manure, pig manure, cattle offal and kitchen leftovers).	Fish diets of house-fly maggots and earth worm meal at 35% protein had overall superior performance. These diets are more cost effective in producing fish and will be affordable to fish farmers. It was concluded that chicken manure was the best substrate tested for maggot production. Further results demonstrated that maggot meal can replace fish meal in the diets without affecting the growth performance of Nile tilapia. Test indicated that the maggot meal has higher protein content and promotes better growth performance than soybean meal, offering great cost saving potential for small-scale fish farmers in Tanzania.
Optimization of a cell phone marketing tool in Ghana	The technology is a cellphone based Fish Market Information System (FMIS) with a focus on tilapia and catfish, and further inclusion of marine fish. For small-scale fish producers and artisanal fishermen in Ghana, readily available market information on prices and demand for fish at different fish markets helps inform production and harvesting decisions. This technology delivers information in 5 languages – English, Twi, Ga, Ewe and Fante and provides information from an online database.	Minimizing the information gaps along the fish value chain greatly improves efficiencies and reduces post-harvest losses in the value chain as a whole. The development of this technology has been a successful pilot program, providing fish farmers and fishermen with easy access to prices on tilapia, catfish, and several marine species. FMIS has provided users with the information needed for value chain agents to operate more efficiently and to more effectively support urban markets. Continued development and improvements to the existing FMIS framework will expand its ability to address the diverse information needs of various stakeholders and expand adoption.
Optimizing the use of commercial feeds in semi-intensive tilapia production in Ghana	Compared growth and yield of Nile tilapia in grow-out ponds with a 30% protein commercial diet at a full ration, half ration, and alternate-day full ration all with fertilization to determine if reduced feeding strategies can offer cost-saving opportunities for fish farmers in Ghana.	Over a 15-week experimental period testing feed reduction strategies revealed that reducing feeds by half or feeding on alternate days did not affect fish growth and nutrient conversion efficiency. These results indicate that farmers can reduce feed and thus reduce production costs. The alternate day feeding strategy resulted in the greatest cost saving.
Experimental diets to help improve feed efficiencies in tilapia production in Ghana.	Previous studies have shown that agro-industrial by products in Ghana can offer a good supplementary protein source for tilapia diets. Three experimental diets were developed, primarily made from agro-industrial by-products that were fermented to improve the nutritional quality of the ingredients. The three diets were tested in a series of experiments and economic analyses to develop a locally verified	Experiments to evaluate fish growth, survival, acceptability, palatability, and profitability revealed two of the three experimental diets demonstrate further opportunities to reduce feed costs, increase incomes, and improve the sustainability of tilapia production in Ghana. The key impact is a reduction in the production cost by lowering feed cost; this will ultimately

Technology	Description	Key Impact
	knowledge base on cost-saving options for fish feeds and feeding strategies for pond-based tilapia producers in Ghana.	increase the profitability of semi-intensive pond tilapia farms.

Africa Project: Kenya & Uganda

Project Partners and Collaborators

Auburn University (US Project University); Alabama A&M University; University of Arizona; University of Eldoret; Kenyatta University; National Fisheries Resources Research Institute (NaFIRRI, Lead HC Institution); Makerere University; AgroMarketDay; Fisheries Training Institute; Gulu University; Kenya Ministry of Agriculture, Livestock, and Fisheries; Mwea Aquafish Farm; Egerton University; Karatina University; Kenyan Marine and Fisheries Research Institute; County Government of Kirinyaga; and Walimi Fish Cooperative Society Ltd.

Technology	Description	Key Impact
Low-cost captive breeding and hatching of African lungfish in Uganda	African lungfish (*Protopterus aethiopicus*) supports many communities in Uganda, and has aquaculture potential in the East African region. Fish farmers access seed from natural environments, which is not sustainable, environmentally and economically. This study explored the genetic diversity of *P. aethiopicus* collected from Lakes in Uganda to inform its future breeding programs. Results generated information to guide the domestication of African lungfish in the region for improving nutrition and livelihoods of vulnerable communities in Uganda.	The full development of this technology is contributing to the domestication of the African lungfish and is helping to ensure the environmentally sustainable supply of lungfish seed for a new culture industry. Further, governmental and regional management bodies can now develop policies that will ensure protection of lungfish and communities dependent in this resource.
Cell phone application for small & medium scale fish farmers	Marketing and information tool developed through a program of technical collaboration among researchers, government technical staff, and cellular providers to advance aquacultural development. Through the availability of a text-based system, farmers have access to fish market and fingerling supply information. This results in better prices, less risk, better information, and facilitates access to key inputs.	The successful development of the "Aqua-Application" is helping to alleviate bottlenecks in Ugandan aquaculture, bridging the information gap for fish farmers, fishermen, and fish sellers regarding production and market information. The app currently allows more contacts amongst farmers, enables exchange of information any time the need arises, and enables contact with customers more easily, which saves time and other transaction costs. Farmers are able to get daily market price information from across the entire country, and producers are able to price their products appropriately.
Low-cost aquaponics for a mediums scale unit in Kenya	The medium-scale aquaponics system developed in this study can be used to raise both fish and crops within the tropical climate and especially in water deficient East Africa.	The development of a prototype aquaponics system that can be used to raise both fish and crops within the tropical setup and especially in water deficient East Africa. The unit offers good opportunities for rapid commercialization by the private entrepreneurs but there is need to improve on energy requirement, potentially through solar technology.
Practical fish feeds for Western Kenya	Developed formulated diets using locally available ingredients that provide balanced essential amino acids (EAAs) to enhance both the physical quality and the nutritive value of the fish	One possible solution to the lack of available feed in East Africa is for fish farmers to formulate their own feeds in the farm so as to guarantee the desired quality. This study has

Technology	Description	Key Impact
	feed. Results showed diets supplemented with the amino acid, lysine, resulted in faster tilapia growth rates. All experimental feeds containing EAAs supported faster tilapia growth than the readily-available but expensive commercial feeds. Farmers can incorporate these new feeds with minimal investment.	shown that the feed formulation, processing and nutritional balancing can be achieved through supplementing the diets with essential amino acids, as these are often the limiting factors in tilapia feed performance. Results demonstrated that on-farm diets can produce superior production parameters as compared to commercial fish feeds in Kenya.
Enhancing the nutritional value of tilapia through innovative feed formulation	The study generated information on practical diet development for Nile tilapia in Ghana towards the production of a fish with a healthier lipid profile (enriched in omega-3/n-3 fatty acids). Production of healthier tilapia is part of a larger strategy to improve the nutritional status of people in developing countries.	A total of 23 oilseeds were identified in the Upper East, Brong-Ahafo, Ashanti and Greater Accra regions of Ghana. However, none of the ingredients contained significant amounts of n-3 fatty acids (<0.5%), so a supplemental lipid such as linseed oil was tested in the diets to enrich the fish and their human consumers with n-3 fatty acids. Results showed a significant difference in n-3 fatty acids in fish flesh fed linseed oil than all the other diets, as well as the initial fish stock.

VIII. ENVIRONMENTAL MANAGEMENT AND MITIGATION (EMMP)

Excerpted from RFA # M/OAA/EGAT-06-1395, Initial Environmental Examination (IEE); and amended in March 2013

The AquaFish Innovation Lab leads innovative research, training, and capacity building activities designed to develop and disseminate technologies, tools, practices, methodologies and policies that will sustainably increase aquaculture production; maintain and restore capture fisheries productivity; prevent and reduce poverty among subsistence and small-scale farmers and fishers; help prevent further degradation of aquatic ecosystem health; and protect valuable aquatic biodiversity. The AquaFish IL ME ensures that environmental issues are considered and incorporated into research, training and outreach activities. To this end, USAID determined that a categorical exclusion (under 22 CFR 216) was appropriate for all activities implemented under the AquaFish Leader Award given that projects and the overall program comply with the environmental restrictions listed below. These restrictions are included in all AquaFish solicitations for research and resulting subcontracts.

Environmental Restrictions:

- Biotechnical investigations will be conducted primarily on research stations in Host Countries.
- Research protocols, policies, and practices will be established prior to implementation to ensure that potential environmental impacts are strictly controlled.
- All training programs and outreach materials intended to promote the adoption of AquaFish IL-generated research findings will incorporate the appropriate environmental recommendations.
- All sub-awards must comply with environmental standards.
- AquaFish IL Projects will not procure, use, or recommend the use of pesticides of any kind. This includes but is not limited to algaecides, herbicides, fungicides, piscicides, parasiticides, and protozoacides.
- AquaFish IL Projects will not use or procure genetically modified organisms (GMO).
- AquaFish IL Projects will not use, or recommend for use, any species that are non-endemic to a country or not already well established in its local waters, or that are non-endemic and well established but are the subject of an invasive species control effort.

Further, it was determined that a negative environmental threshold determination with conditions was appropriate. These conditions relate to the use of pesticides, GMO and non-indigenous or non-endemic non-established species.

IX. OPEN DATA MANAGEMENT PLAN

Open Data Policy
In accordance with the Office of Management and Budget (OMB) Open Data Policy (M-13-13) pursuant to Executive Order 13642 issued by the President on 9 May 2013 (*Making Open and Machine-Readable the New Default for Government Information*) and the Office of Science and Technology Policy's (OSTP) 22 February 2013 memo (*Increasing Access to the Results of Federally Funded Scientific Research*), the AquaFish Innovation Lab developed an Open Access Policy to increase access to data and results of federally funded scientific research.

The AquaFish Innovation Lab Open Access Policy should be implemented by AquaFish IL Lead Project PIs with the intention of providing opportunities for leveraging existing data, fostering public-private partnerships, improving the public's ability to locate and access data from federally-funded scientific research, and ensuring the long-term stewardship of these data. The policy aims to provide broader public access and improve the impact and accountability of the federal research investment in the AquaFish IL.

Improving the accessibility of AquaFish IL data and results can more effectively bring the program, its partners, and other stakeholders a more complete and timely understanding of development programs. By making data and results available through user-friendly platforms in machine-readable formats, host countries, scientists, and communities can propel research forward in solving the complex development problems of our time.

Data Management Plan
In FY16, each AquaFish IL project developed a plan outlining research datasets that are expected to be of sufficient quality to produce *intellectual work*, defined here as a scholarly peer-reviewed publication, during the 2016-2018 Implementation Plan. Individual project plans were combined to comprise the AquaFish FY17 and FY18 Data Management Plans (DMP), approved by USAID AOR.

In FY18, the AquaFish Management Team (MT) continued to track on USAID's data policy, and established a process and mechanisms for subcontractors to comply with the policy. The MT built an online AquaFish IL data repository using Dataverse to aid AquaFish IL researchers in submitting their completed datasets. While subcontractors had been notified of USAID's data policy on numerous occasions, it is a complex policy and challenging to implement, and thus necessitated the MT to continue working closely with project partners in FY18 to ensure compliance.

AquaFish projects reported that 10 datasets were uploaded to public data repositories and registered with the Data Development Library (DDL) in FY18. As noted, all project partners have been informed of USAID's data requirements and are aware that data must be uploaded to a public repository and metadata reported to the USAID DDL no later than 23 September 2018, five days prior to termination.

X. GOVERNANCE AND MANAGEMENT ENTITY ACTIVITY

Oregon State University (OSU) serves as the Management Entity (ME) of the AquaFish Innovation Lab. The vision and leadership for the programmatic, technical, and fiscal performance of the program is set by the AquaFish IL's Director and Lead Principal Investigator, Dr. Hillary Egna. This vision is consistent with USAID's goals to create and nurture strong global partnerships for promoting lasting development that improves health, builds wealth, conserves natural environments for future generations, and strengthens the ability of host countries to self-govern in a way that respects the sanctity of all. The ME houses the AquaFish Innovation Lab Management Team (MT) comprised of the Director and her staff, which is responsible for AquaFish Innovation Lab operations, management, reporting, and communications among its partners, stakeholders, and the interested public. In support of the overall AquaFish Innovation Lab mission and to expand the reach of the program, the MT engages in research, education, outreach, and capacity building activities related to sustainable aquaculture and fisheries with core funds designated by USAID for aquaculture.

In FY18, the MT continued to monitor all program activities and deliverables, establishing research accountability and evaluating achievements. A meeting was held in conjunction with Aquaculture America 2018 conference in Las Vegas, which allowed for continued planning for project closedowns and offered opportunities for partners to strengthen their networks with international experts in their fields. The MT also organized a meeting for EPAC and RCE coordinators while in Las Vegas to review priorities and methods to ensure successful closedown at the end of FY18. Routine Skype and conference calls with US and HC partners throughout FY18 provided check-ins to discuss progress of AquaFish IL work related to reporting, funding, upcoming opportunities, and challenges. The MT continued to monitor and evaluate project success via quarterly reporting and the FTF monitoring system and held two meetings in FY18 with the Emerging Issues Panel to ensure graceful closedown at OSU. The AquaFish IL held a series of final meetings in conjunction with the AQUA 2018 conference in Montpellier, France, including two advisory team meetings (EPAC and RCE), two regional meetings, and one program meeting.

The AquaFish IL MT communicated with USAID regularly and passed along policy and protocol changes to partners to ensure compliance. The MT also maintained regular communication with the AquaFish IL Agreement Officer's Representative at USAID, Dr. Shivaun Leonard, and fielded numerous data requests, serving as an effective liaison for our partners to reduce administrative burden and allow them the time to work towards program objectives.

As one of 24 Innovation Labs, the AquaFish IL recognizes the importance of inter-lab relationships and communication in tackling root causes of food insecurity and poverty by employing proven strategies for achieving large scale and lasting impacts. To this end, the AquaFish IL continued to work with other Innovation Labs, including participating in the first ever International Sustainable Agricultural Intensification and Nutrition conference in Cambodia. This conference was hosted by the Innovation Lab for Sustainable Intensification and offered the AquaFish IL the opportunity to present research results to other Innovation Lab partners and to learn about similar efforts to develop technologies that improve food security and agriculture efficiency. The MT also participated in the Innovation Labs Council Meeting in Senegal and the World Food Prize, allowing the AquaFish IL to connect with other programs and foster new international development relationships that further expand its collaborative network. In FY18, the AquaFish IL MT also worked with USAID and the University of California at Davis (home of the

Horticulture Innovation Lab) to support and facilitate two FTF Innovation Lab events: Innovation Lab meetings in Uganda (May 2018) and in Washington, DC (September 2018).

Capacity building is a cross-cutting element for the AquaFish IL that strengthens long-term program impacts at community and national levels. In addition to programmatic and project-level support of short- and long-term trainees, the AquaFish IL MT engages in mentorship and support of scientists, both during school and after graduation. In FY18, the AquaFish IL honored five students with the *AquaFish Student Abstract Award for International Development* and three students with the *AquaFish/USAS Best Student Abstract Award* at Aquaculture America 2018. Three students received *AquaFish Best Student Papers on Aquaculture Economics* at the International Institute of Fisheries Economics & Trade conference in FY18, and the AquaFish IL supported three undergraduate students and one graduate student from OSU's College of Agricultural Sciences to attend the annual conference of the Association for International Agriculture Research and Development.

The MT is responsible for engaging in outreach and dissemination activities that facilitate communication, publicize results and technologies, and create new linkages. In FY18, the AquaFish IL Director organized an all-day technical session at Aquaculture America 2018. Immediately following the conference, the MT organized and sponsored 30 international visitors from universities and government research institutions from 11 countries to visit OSU. To foster global connectedness, the AquaFish IL invited OSU faculty and leadership to a networking luncheon, an informal "meet & greet" in cooperation with OSU Department of Fish & Wildlife, and field visits to nearby research facilities. These activities broaden the AquaFish IL's reach and promote collaborative relationships for AquaFish IL partners. The AquaFish IL also disseminated information widely in FY18 through flagship newsletters and publications, including the AquaFish Eleventh Annual Report, Technical Report, three issues of the *AquaNews* newsletter, and nine issues of the employment opportunity newsletter (*EdOpNet*). In addition, the MT continued to update the program website, and respond to public inquiries about AquaFish IL activities and opportunities. While in Montpellier, France, for the AQUA 2018 conference, the AquaFish IL organized and chaired a panel session to discuss the future of sustainable aquaculture. Filmmakers from OSU attended the conference as well, and interviewed past and current AquaFish IL students and partners for a video series focusing on the successes of AquaFish IL HICD work and activities.

AquaFish IL partners tour OSU and neighboring research facilities in February 2018.

In addition to AquaFish IL partners' publications and presentations (see *Section V*), the AquaFish IL MT continued to reach out to various stakeholder groups and share information via publications, presentations, and exhibitions at conference and community events, including:

- Borberg, J., S. Ichien, A. Hyman, C. Ensminger, and H. Egna. 2018. A Review of Over a Decade of Global Investment in Aquaculture Feed Technologies. [Oral Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Borberg, J., S. Ichien, L. Carroll, and H. Egna. 2018. Addressing Undernutrition through Sustainable Aquaculture Development in Southeast Asia. [Poster Presentation]. International Sustainable Agricultural Intensification and Nutrition, Phnom Penh, Cambodia, 10-13 January 2018.
- Carroll, L., K. Goetting, S. Ichien, and H. Egna. 2018. Local, Regional, National, and International Benefits of Stakeholder Involvement in AquaFish Innovation Lab Research. [Poster Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Chow, M., H.S. Egna, and J. West. 2017. Towards Assessing Gender Aquaculture Publications Authorship. Asian Fisheries Science Special Issue 30S:129–141.
- Chow, M., H. Egna, and J. West. 2018. Which Author is Which? Gender Authorship Position as Proxy for the Status of Gender Integration in Aquaculture Literature. [Oral Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Chow, M., H. Egna, and J. West. 2018. Which Author is Which? Gender Authorship Position as Proxy for the Status of Gender Integration in Aquaculture Literature. [Poster Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Evans, F., K. Goetting, H. Demmin, and H. Egna. 2018. Supporting Development of Non-Fed, Low-Trophic Aquaculture Systems to Address Food Security and Economic Growth in Coastal Communities in Africa, Asia, and Latin America. [Poster Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Hyman, A., A. Dew, M.H. McCormick, S. Ichien, J. Borberg, K. Goetting, and H. Egna. 2018. Improving Climate Resilience through the Culture of Native and Adaptive Species. [Poster Presentation]. Oregon Chapter of the American Fisheries Society 54th Annual Meeting, Eugene, Oregon, 13-16 March 2018.
- Hyman, A., C. Ensminger, S. Ichien, and H. Egna. 2018. Data Management in Aquaculture: Abiding by the US Federal Mandates. [Poster Presentation]. Aquaculture America, Las Vegas, Nevada, US, 19-22 February 2018.
- Hyman, A., L. Carroll, R. Pomeroy, and H. Egna. 2018. Research Informs Policy to Lift Cambodian Snakehead Farming Ban. [Poster Presentation]. International Sustainable Agricultural Intensification and Nutrition, Phnom Penh, Cambodia, 10-13 January 2018.
- Ichien, S., A. Hyman, T.T.T. Hien, F. Evans, and H. Egna. 2018. Research Innovation Actions Across Watersheds and Countries: Collaboration Between Cambodia and Vietnam on Sustainable Snakehead Aquaculture. [Poster Presentation]. International Sustainable Agricultural Intensification and Nutrition, Phnom Penh, Cambodia, 10-13 January 2018.
- Ichien, S., J. Borberg, and H. Egna. 2018. A Geospatial Analysis of Social and Ecological Tradeoffs of Air-Breathing Fish Aquaculture for Decision Making in a Changing Climate. [Poster Presentation]. International Sustainable Agricultural Intensification and Nutrition, Phnom Penh, Cambodia, 10-13 January 2018.

AquaFish IL Director, Dr. Hillary Egna, was a co-author on many FY18 publications and presentations, which can be found in *Section V. Research Project Reports*.

In FY18, the MT continued to effectively manage a large cooperative award, ensure compliance and transparency in research, and work in concert with FTF objectives. The productivity for FY18 highlighted above and throughout this report shows examples of how the AquaFish IL has fulfilled its obligations to provide programmatic, technical, and fiscal leadership and to disseminate research results and programmatic information to global audiences.

XI. OTHER TOPICS

GENDER INITIATIVES AND ACCOMPLISHMENTS

Gender equality and female empowerment are core development objectives of the USAID research agenda and are fundamental to accomplishing effective and sustainable development outcomes. Gender integration involves identifying and addressing inequalities due to gender. These inequalities are addressed during the project design process and throughout the implementation, monitoring, and evaluation processes. AquaFish IL integrates women into aquaculture research and outreach through both direct interventions and cross-cutting efforts in capacity building, economic development, agricultural development, food security, and poverty alleviation—key issues targeted by USAID's Feed the Future initiative.

The AquaFish IL took a holistic approach to integrating women into all programmatic activities, with a goal of extending gender equity beyond the life of any given project and of the AquaFish IL program itself. Each research project included a Gender Inclusiveness Strategy and at least one investigation that focused specifically on women or girls. Gender equity was a major focus of the AquaFish IL capacity building efforts, with a goal of involving equal numbers of men and women in training activities such as formal education, workshops, and conferences; as well as in institutional strengthening efforts including within the program itself (as project investigators, researchers, administrators, leaders). Gender disaggregated data were collected and analyzed to inform project management, policy, and capacity building needs.

In FY18, women represented 44% of the AquaFish IL short-term trainees, who acquired knowledge and specialized skills in aquaculture and fisheries through workshops and other training events; and 48% of the AquaFish IL supported long-term students who earned academic and professional degrees. These training experiences were developed to help strengthen their ability to earn income, improve household nutrition, and contribute to aquaculture development in their respective communities. Improving gender equity at the institutional level and ensuring that women are included in leadership is central to the long-term benefits of gender integration. Social and cultural barriers can pose challenges to meeting the 50% gender benchmark, and the AquaFish IL works with US and Host Country researchers, extension agents, and others to overcome these obstacles.

Gender Integration Initiatives

FY18 accomplishments towards the AquaFish IL Gender Integration Initiatives (highlighted with the green background) are presented in the table below. These gender initiatives were a component of the AquaFish IL USAID-approved Monitoring & Evaluation Plan.

Years 2-5 Initiatives:
Collect disaggregated gender data from individual research and outreach projects funded by the AquaFish IL.
Data collected for short-term and long-term training activities was disaggregated by gender for the life of the project.
Analyze disaggregated data on an annual basis to gauge gender inclusiveness success and take appropriate action as indicated through data analysis.

Since program inception in 2006, gender disaggregated data were analyzed annually to gauge gender inclusiveness and success (see section *XII. Human and Institutional Capacity Development* of this report for more information). To help facilitate success, women's participation was integrated at the planning stage for all sponsored projects, utilizing context-based circumstances and information to anticipate and overcome obstacles on the ground.
Involve field projects in monitoring and evaluating gender integration as the program progresses with time. Evaluate the effects of specific projects on gender and ensure that any possible negative effects due to gender bias are mitigated.
Gender integration was a cross-cutting issue addressed by all AquaFish IL projects. Gender Inclusiveness Strategies identified specific project approaches at the start of each project, whereby PIs and researchers in the US and Host Countries were involved in monitoring and evaluation throughout the research process. Investigations involved a tailored approach that considered conditions on the ground to help ensure success, with particular attention to women's involvement and mitigating any negative effects.
Focus one component of a lessons learned and synthesis assessment specifically on the social context and impact of AquaFish IL research and outreach activities on the lives of women.
The AquaFish IL communicated gender activities and accomplishments through conference presentations, posters, AquaNews articles, and other media. In FY18, the AquaFish IL produced and gave the following gender-focused publications and presentations: ● Atukunda, G., J.J. Molnar, M. Matuha, T. Hyuha, J.K. Walakira, S. Namatovu, and G. Abalo. 2018. Institutional and Household Factors in Promoting the Role of Women in Aquaculture Value Chain in Uganda. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018. ● Carroll, L., K. Goetting, S. Ichien, and H.S. Egna. Local, Regional, National, and International Benefits of Stakeholder Involvement in AquaFish Innovation Lab Research. [Poster Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018. ● Chow, M. and H.S. Egna. 2018. Which Author is Which Gender Authorship Position as A Proxy for the Status of Gender in Aquaculture Literature. [Poster and Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018. ● Chow, M., H.S. Egna, and J. West. 2017. Towards Assessing Gender Authorship in Aquaculture Publications. Asian Fisheries Science Special Issue (30S):129 - 141. ● Jha, S.K., S. Rai, M.K. Shrestha, J.S. Diana, R.B. Mandal, and H.S. Egna. 2018. Production of periphyton to enhance yield in polyculture ponds with carps and small indigenous species. Aquaculture Reports. 9:74–81. ● Haque, S.M., M.N. Hoque, and S.M. Haque. 2018. Status of Women in Different Socio-cultural Context of Aquaculture Based Societies: A Case Study from Bangladesh. [Poster Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018. ● Haque, S.M., S.B. Satu, M.M. Rahmann, H.S. Egna, S. Salger, and R.J. Borski. December 2017. Improving the Livelihood for Marginalized Women's Households in Southwest Bangladesh through Aquaculture. Asian Fisheries Science Special Issue (30S):313 - 326. ● Hien, H.V., Quyen, N.T.K., Phu, T.M., Hien, T.T.T., Due, P.M. 2018. Survey of fish consumption by women and children in An Giang province. Journal of Vietnam Agricultural Science and Technology. 86(1): 106-112. ● Rai, S., M.K. Shrestha, J.S. Diana, and H. S. Egna. 2018. Involving Women in Field-Testing of a Periphyton Enhanced Aquaculture System for Nutrition Security. [Oral Presentation]. Aquaculture America 2018, Las Vegas, Nevada, 19-22 February 2018.
Tailor specific extension and technical services related to sustainable aquaculture and aquatic resource management to women producers.
The AquaFish IL tailored specific interventions to empower women through information and access to networks and resources. For example, in FY18, the AquaFish IL held nine workshops in

Nepal, reaching a total of 174 women. Four workshops were on aquaculture and its role in household nutrition specifically for women's groups, reaching a total of 79 women in two different regions; and five trainings were on enhancing the natural productivity of ponds to reduce feed requirements (periphyton enhancement), reaching 95 women.
Engage extension specialists who are sensitive to diversity issues and access to resources of underrepresented groups and women will be included as an integral part of their delivery team to ensure women farmers and fishers feel welcome in AquaFish IL training opportunities.
As proposed, efforts were made to ensure women farmers were welcome at trainings. In FY18 the AquaFish IL conducted a survey and interviews in Uganda with fish farmers, leaders of fish farmers associations, and aquaculture extension workers, to evaluate women's participation in various segments of the value chain and constraints to their involvement. Based on survey and interview findings, 18 women were trained on fish production, nutrition, and markets in Uganda. Additionally, each AquaFish IL project included women in key positions, serving roles such as investigators, research collaborators, and workshop leaders.
Promote the participation of women in formal and informal education and training opportunities provided through AquaFish IL. The AquaFish IL has set a 50% benchmark for training women in formal and informal education. In addition, the 50% benchmark applies to attracting and retaining women scientists and administrators in all AquaFish IL activities, as project researchers, advisory group members, and managers.
During FY18, women represented 44% and 48% of the AquaFish IL short and long-term trainees, respectively, with program efforts reaching 347 women in short-term trainings and 73 women in long-term training degree programs. Women were represented as key personnel on AquaFish IL projects, Advisory Groups, and in program management.

Gender-Focused Research and Outreach

Highlights of FY18 gender-focused work for the AquaFish IL are included below.

Africa Project: Ghana & Tanzania

- In FY15 and FY16, the AquaFish IL developed a service called the Fish Market Information System (FMIS) in Ghana, a web-based tool that provides tilapia market information online as well as via voice and text messaging. The database was populated with the prices at which fish are sold by the farms (farm-gate pricing) and market data for tilapia from several locations throughout the country. In FY18, the AquaFish IL expanded the application to marine fish and markets in five different languages. There have been over 1,000 downloads of the application. This research will have gender impacts in the value chain, as most fish sellers and marketers in Ghana are women.

Africa Project: Kenya & Uganda

- In Uganda in FY18, the AquaFish IL developed and strengthened relationships with local partners to increase the capacity of partner organizations to address barriers to women's involvement in aquaculture. These local partner organizations included fish farmer cooperatives, women's aquaculture organizations, and industry. The number of training and outreach events targeting women increased, improving women's access to aquaculture information on fish production, nutrition, and marketing.

Asia Project: Bangladesh

- Women continued to be integrated in all levels of the AquaFish IL work in Bangladesh in FY18. Three women host country researchers from the Bangladesh Agricultural University played key roles in conducting research and outreach, with one serving as the HC Project PI. As part of this effort, researchers in Bangladesh found that the addition of mola in prawn-gher farming systems

showed no negative impact on the production of prawn, but enhanced the total production of fishes. Integration of mola allowed continuous consumption of this nutrient dense fish, helping to mitigate nutritional deficiencies and increase food security of smallholder households, many of which are homes where the women are the primary caregivers.

Asia Project: Cambodia & Vietnam

- Research in Cambodia found aquatic animals to be the second largest staple food for women and children during the wet season, contributing on average 49% of the protein consumed by women and 41% of the protein consumed by preschool-aged children. As the wet and dry seasons are vastly different in this region, the AquaFish IL expanded on this work in FY18 to establish food consumption patterns in Cambodia and Vietnam during the dry season. Results showed that during the dry season many women and children did not meet the recommended intake of protein. During both the wet and dry season, however, fish and other aquatic animals were a primary source of protein and micronutrients, such as iron, zinc, calcium, and vitamin A, in the diets of women and children in Cambodia and Vietnam.

Asia Project: Nepal

- AquaFish IL research in Nepal on periphyton enhancement in carp and small indigenous fish species (SIS) polyculture, led by a host country investigator who received her PhD under the Aquaculture CRSP, continued in FY18 in collaboration with women fish farmers. The use of periphyton enhancement was previously shown to improve water quality discharged from ponds and increase net fish yield and profit in carp-small indigenous fish species polyculture. In FY18, this research continued and involved 15 women from the Sunderdeep Women's Fish Farmer's Cooperative who joined 12 men and 3 additional women from the Mishrit Cooperative. The group tested five different substrates for boosting periphyton growth and improving in-pond productivity and determined that fish production, gross margins, and gross returns for the ponds with substrates were higher than the controls.

AquaFish IL Management Team

- The AquaFish IL Director, Dr. Hillary Egna, worked with the Gender in Aquaculture and Fisheries (GAF) section of the Asian Fisheries Society to develop a strategy for the future. The AquaFish IL MT also sponsored GAF in FY18 (as in previous years) as part of a global initiative.

REGIONAL CENTERS OF EXCELLENCE (RCE) ANNUAL REPORTS

The AquaFish Regional Centers of Excellence (RCEs) in Africa, Asia, and Latin America and the Caribbean have continued to strengthen community among AquaFish participants; identify potential new partnerships with the public and private sector, NGOs, USAID, and others; and bridge the knowledge gap from local and regional perspectives to global development outcomes. With a focus on graceful exits as AquaFish approaches closedown, the external advisors provided invaluable input through their participation in FY18. The following information was provided by RCE Coordinators, listed under *Technical and Advisory Committee Information*.

RCE – Africa: *Charles Ngugi* (East Africa) & *Steve Amisah* (West Africa)
RCE – Asia: *Yuan Derun* (Southeast Asia)
RCE – Latin America & Caribbean: *Wilfrido Contreras-Sanchez* (Central America and the Caribbean) & *Maria Célia Portella* (South America)

RCE – Africa Annual Report

Regional Needs for Aquaculture Development and Gaps in Technology Transfer and Adoption

Aquaculture development continues to be hindered in several African countries due to limited access to feeds, lack of quality seed, a focus on capture fisheries, inadequate infrastructure, and limited access to information and extension services. There are several country-specific constraints for aquaculture, such as political instability, unsustainable mining techniques, and the socio-cultural status of women. Youth unemployment and underemployment are also critical issues facing Sub-Saharan Africa (SSA). Though urbanization and industrialization have expanded, agriculture, including aquaculture remains the principal employer and producer throughout SSA. Thus, a more modern and profitable agriculture sector (including aquaculture, fisheries, forestry, and livestock) is required to generate much needed employment opportunities for the continent's youth.

Activities that Support Women's Involvement in Aquaculture and Fisheries

Women's roles in aquaculture vary throughout Africa and are often correlated with the socio-cultural roles of women in the specific regions. Women and youth often face barriers to their participation in the agriculture sector, including inadequate access to education, employment, and decision-making capacity. RCE coordinators have encouraged HC PIs to offer more scholarships for women, organize women-specific trainings, and supported and encouraged women involvement in the newly formed Africa Chapter of the World Aquaculture Society. The RCE coordinator trained young women and men in pond aquaculture technologies in a collaborative effort with the Food and Agriculture Organization (FAO).

Capacity Building and Information Dissemination

The Africa RCE reached a range of audiences in its dissemination strategy, each requiring varying levels of investment and different approaches for effective communication. Specific approaches included:

- Assisting with the formation of the Aquaculture Network of East Africa (ANEA), to share knowledge and transfer technologies within the region.
- Maintaining an Africa RCE Web Page (http://rceafrica.com/; the network is also accessible on Facebook and Twitter). When the AquaFish IL closes, the Africa RCE will be used to help support ANEA.
- Fostering intra-Africa collaboration – The RCE Coordinators have engaged with contacts in Ghana, Kenya, and Malawi and has applied for an African Union Grant. Additionally, the RCE is assisting in the formation of the Aquaculture Association of Tanzania.
- Fostering international collaboration - The RCE Coordinators have engaged with funding agencies in collaborative research with Finland, Denmark, and Ghana to apply for several grants.
- Networking with global scientists interested in African aquaculture through ISTA, SARNISSA, WAS, NEPAD, ANAF, and other meetings and conferences.
- Networking at professional conferences, for example, the Aquaculture America 2018, which was held in Las Vegas, Nevada, USA, and AQUA 2018 in Montpellier, France.
- Engaging stakeholders in the region to develop and adopt new aquaculture technologies.
- Assisting with the formation and delegation of the World Aquaculture Society Africa Chapter.

Leveraged Activities

The Africa RCE has been an active participant in engaging various organizations and governments to leverage aquaculture development. Funds were leveraged from the Danish International Development Agency to support several graduate students at KNUST. The RCE is in the process of applying for funds through the Erasmus+ call for proposals with funding from the European Union, which would support research, training, and exchange of academic staff and students in bio-economy, fisheries, aquaculture, and renewable natural resources. The Ministry of Agriculture, Livestock and Fisheries (Kenya) partnered with FAO to implement a three-year program from October 2014 to December 2017. This program aimed

at creating employment opportunities for young women and men in aquaculture and to improve their income and access to food, including fish products in the local markets. In Kenya and Tanzania, the RCE is working with researchers from the University of Stirling, UK, and fish farmers with support from the Scottish Association for Marine Science on a project entitled 'Sustainable New Ingredients to Promote Health,' which aims to utilize affordable, local ingredients to increase essential nutrients in fish feed. In Uganda, there are a number of collaborative programs across the country working with NGOs, universities, and research institutions on best management practices for cage and pond aquaculture.

RCE – Asia Annual Report

Regional Needs for Aquaculture Development and Gaps in Technology Transfer and Adoption

The main aquaculture research needs in the Asia region are for new and improved technologies, specifically, to optimize farming systems through increased ecological efficiency, reduced environmental impacts, and increased profitability. Additionally, more effort is needed to better understand how to monitor and manage fish health. Countries with less developed aquaculture industries need more effort put into fish feeds and seed production. The challenge remains of increasingly stringent production requirements to meet food quality and safety standards. Finally, there is a general need to improve the accountability, effectiveness, efficiency of aquaculture governance, especially within the context of addressing climate change mitigation and adaption.

Activities that Support Women's Involvement in Aquaculture and Fisheries

The RCE Asia is affiliated with the Network of Aquaculture Centres in Asia-Pacific (NACA), an intergovernmental organization that promotes rural development through sustainable aquaculture. Currently NACA is carrying out several activities that support women's involvement in aquaculture and fisheries, including training on gender assessment; policy advocacy for more gender sensitive policies; assessment of gender policies and programs for aquaculture; identifying advocates for campaigning and implementing such policies and programs; developing training courses focused on women's needs in farm management and record keeping; and creating gender sensitive curriculum for institutions. NACA is also working with GAF to develop outreach strategies that showcase the importance of gender in fisheries and aquaculture.

Capacity Building and Information Dissemination

The Asia RCE coordinator was involved in the following outreach and dissemination activities in FY17:

- Continuing training focused on developing culture-based fisheries in Cambodia.
- Aiding in the development and translation of guidebooks in English to local languages for farmers of small-scale aquaculture.
- Presenting at the AquaFish Regional Meeting and attending the World Aquaculture Society conference in South Africa.
    - Derun, Y. 2017. Shifting Dynamics of Aquaculture in Asia and Inclusion of Small-Scale Farmers. [Oral Presentation]. AquaFish Asia Regional Meeting, Bharatpur, Nepal, 28 February – 4 March 2017.

Leveraged Activities

The Asia RCE coordinator was involved in the following outreach and dissemination activities in FY18:

- Building regional capacity for aquaculture development through training and education with several partner institutions, including conducting an assessment of training needs.
- Aiding in the development and translation of guidebooks for farmers of small-scale aquaculture.

Though current AquaFish work is focused principally in Africa and Asia, the LAC RCE plays an important role in maintaining partnerships between past and present AquaFish collaborators, building capacity, and leveraging resources in the region.

Regional Needs for Aquaculture Development and Gaps in Technology Transfer and Adoption

The aquaculture industry in the LAC is being impacted by economic hardships, causing increases in the cost of equipment and feed ingredients. A major concern in Brazil is the instability in governing bodies and bureaucratic delays causing decreases in research funding and in receiving environmental licenses. These issues have led to farms operating illegally, ultimately disqualifying them from access to credit. Continuing research and training remain the greatest needs in the LAC, specifically on incorporating marine species into the aquaculture industry, managing the spread of shrimp diseases, identifying new ingredients to improve fish diets, developing technologies that enable small-scale farmers, and focusing on challenges faced by fish farmers. In spite of the need, research funds have become increasingly difficult to secure.

Activities that Support Women's Involvement in Aquaculture and Fisheries

Despite many countries in the region having programs to support women, women's involvement in aquaculture in the region continues to be limited almost exclusively to fish processing. One of the RCE coordinators held a training focused on improving capacity in the crab industry; this training was led by another AquaFish IL collaborator from Myanmar and included many women. The AquaFish IL RCE Coordinator for South America, Dr. Maria Portella, serves as a role model for women in aquaculture. She is the current president of World Aquaculture Society and Dr. Portella has given lectures addressing women in science and aquaculture research more specifically. She also recently participated in the CITYFOOD project in Brazil, supporting resilient urban food systems.

Capacity Building and Information Transfer

The LAC RCE coordinators have been involved in the following capacity building and dissemination efforts:

- Participating in regional and international conferences including, serving as program chair, meeting organization, chairing and moderating sessions, and presenting.
- Leveraging funds to support long-term students.
- Serving leadership roles: Dr. Portella was elected as the President of the World Aquaculture Society.
- Facilitating collaboration within Central and South America: worked with FAO-Nicaragua to assist a governmental project for building a marine hatchery to produce common snook fingerlings; offered trainings to hatcheries for native species reestablishment in Guatemala and Nicaragua.
- Guiding policy and management by fostered global collaboration: RCE coordinator is a principal investigator for LARVAplus: an integrative research network for promoting fish larviculture in Ibero-America and is a participant in BlueEcoNet, a German-Brazilian Bioeconomy Research Network focused on the value chain of aquaculture.
- Fostering relationships with industry: RCE coordinator initiated a project with Petrofac that will explore opportunities for fishermen cooperatives for the municipalities of Pueblo Viejo and Tampico Alto in Mexico.

Leveraged Activities and Associate Awards

RCE Coordinators in LAC leveraged funds for student support, professional networking, and lab expansions. Dr. Portella secured leveraged funds to obtain scholarships for students, one specifically for a student to study at Purdue University on aquaponic systems, and complementary funds for two post-doc scholarships related to CITYFOOD. A Productivity Fellowship was continued through CNPq support. Dr.

Contreras-Sánchez secured a grant from FAO to support training on snook aquaculture in Nicaragua, funding from Petrofac supporting fishing cooperatives in Mexico, and from LINDE to conduct aquaculture training for fishermen in Mexico. The LAC RCE has also used leverage funds to support several undergraduate and graduate students.

XII. ISSUES AND CHALLENGES

The process for obtaining a no-cost extension (NCE) from USAID was both complex and arduous. After discussing the need for a one-year NCE with the AOR in March 2017, and subsequent written requests through Summer 2017, OSU put in a formal NCE request in mid-October 2017 for a 9-month no-cost extension to change the end of the AquaFish Innovation Lab's period of performance from 28 March 2018 to 28 December 2018. After consultation and negotiation with staff from USAID's BFS (now BRFS), an agreement was reached on a 6-month no-cost extension, with the period of performance ending on 28 September 2018. We appreciate the considerable effort that our AOR put into shepherding the paperwork through USAID in an effort to obtain close to a dozen required signatures. OSU received Modification 15 to prime award on 7 February 2018, officially extending the award period of performance to 28 September 2018.

USAID, unlike other research organizations such as USDA or NSF, does not automatically allow one-year NCEs. Indeed, getting an extension on a long running project such as AFIL was "an act of god" according to one USAID staff. However grateful AFIL is, the implications of not having early assurance of a one-year NCE caused attrition to occur both at the ME and at subcontracting partners. The lack of certainty and security unfortunately led to loss of capacity, for which remaining personnel ultimately stepped up to cover. The closedown period thus was extremely busy. Dedicated key personnel, researchers, and staff worked long hours to ensure that all deliverables were completed and reported on properly.

The AquaFish Innovation Lab received last minute notices from several subcontracting US institutions that they were not going to fully spend their total allocated budget. The ME recognized early on that subcontracting partners need to pay attention to expenditures as their projects approach their respective end dates. Indeed, during the final years of this award, the Management Team actively engaged with partners –- through visits to US and HC institutions, regional meetings, and regular conference calls directly with US and HC researchers -– to facilitate project progress. A dedicated "close-out" meeting was held in 2017 that involved subcontracting PIs and their financial personnel in order to facilitate a smooth closedown. In spite of best efforts to monitor, underspending reported to OSU was largely unannounced, and in some cases revealed only in the final invoice after the subcontract's period of performance had closed. When announced the ME worked with subcontracting partners to redistribute the balances wisely and in accordance with the grant's mission. It is worth noting that the largest unspent balances were the results of last-minute institutional adjustments (such as changing indirect rates charged on subcontracts over the life of their award) and outside the immediate control of the subcontracting project's PI or the ME.

OSU disclosed the estimated unspent balance to USAID in May 2018. Working with USAID's contract office (Charles Jackson) to redistribute these funds for aligned uses in AFIL, OSU contracted with University of California at Davis (UCD) on a fixed-cost contract. The contract took about three months to be fully executed, yet allowed for UCD to organize two important USAID Innovation Lab meetings in Uganda and DC in FY18.

XIII. FUTURE DIRECTIONS

The aquaculture sector continues to play an increasingly important role in global food security and will be an important player in meeting the onerous challenge of feeding 9.7 billion people by 2050. This challenge, and the role that aquaculture will play, must also be understood in the context of a changing climate, economic and financial uncertainty, and growing competition for natural resources[1].

Fish and other seafood are highly nutritious sources of animal-based protein, and global per capita fish consumption is currently over 20 kg. Global fish production destined for human consumption is expected to continue to grow due to increased demand driven by, among other things, increased affluence and urbanization in developing countries. With global capture fishery landings remaining static since the 1980s, this increased demand for seafood by a growing population will need to be met through aquaculture production.

The overarching challenge for the global aquaculture sector, therefore, is to increase production in a way that is economically viable, environmentally sustainable (including accounting for inputs such as fish meal), and can be accomplished in the face of a changing climate. In the context of international development, increased production must also occur in a pro-poor manner that addresses local needs to improve livelihoods and food security, especially for marginalized populations.

Opportunities exist for USAID to build on the aquaculture development work conducted by the AquaFish IL. In February 2018, USAID released a Notice of Funding Opportunity for the new Fish Innovation Lab to continue global aquaculture development work through 2023 – demonstrating USG commitment to future work in this area. AquaFish IL recommends that USAID carefully consider which parts of the aquaculture sector to support with public funding and which can be best supported by industry and the private sector. Fish in particular are a high value product often exported. Benefits of production accrue unevenly with smaller farms losing out as the sector grows.

Since 1982, a global, multidisciplinary network of aquaculture experts has grown through participation in the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP), the Aquaculture CRSP (ACRSP), AquaFish CRSP, and the AquaFish IL. Significant opportunities exist for future development efforts to draw on the aquaculture expertise within this network. With this in mind and in order to ensure continued and lasting impacts of the work initiated by the AquaFish IL, during FY17 and FY18 a high priority was to ensure that over a decade of AquaFish-supported research and capacity building was transferred to host countries so that project partners can continue to build on and carry work forward. To accomplish this, AquaFish IL focused on outreach and dissemination to transfer knowledge and technologies to HC researchers, extension agents, farmers, industry personnel, managers, policy makers, and other stakeholders. Each project developed an Exit Strategy in FY16 describing a plan for a graceful exit after the AquaFish IL end date. The AquaFish IL MT worked with project partners to monitor progress towards these strategies to assist with seamless transitions to our HC partners. As a result, important, host country-led research, initiated with the support of AquaFish IL, is continuing to advance the development of the aquaculture sector to improve livelihoods and food security.

[1] FAO. 2016. The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200 pp.

APPENDIX A: SUCCESS STORIES

CONDITIONING JUVENILE TILAPIA FOR IMPROVED GROWTH AND HEALTH OUTCOMES IN BANGLADESH

by Caleb Price, Kathryn Goetting, and Hillary Egna

The Nile tilapia (*Oreochromis niloticus*) is one of the most widely cultured fish species in the world. In Bangladesh, aquaculture of tilapia has expanded rapidly over the last 20 years, and has become an increasingly important source of protein for the nation's poor. But the costs of growing tilapia, particularly the cost of feed, can be prohibitive with feed accounting for up to 80% of production costs.

As a result, many farmers in Bangladesh raise tilapia without using feed. Instead, following older technologies developed in large part by the PD/A CRSP (an USAID program from the 1980s), they fertilize their fish ponds to promote primary production, a natural food source for tilapia. Though this approach allows farmers to reduce overhead costs, it also limits economic returns since non-fed tilapia grow at a slower rate than fish fed commercial diets.

The AquaFish Innovation Lab (AquaFish IL), a USAID-funded program based at Oregon State University that helps to improve aquaculture practices in developing nations, has identified strategies that reduce the use of expensive feeds while increasing production and income for small- and mid-scale fish farmers.

Analysis of Nile tilapia gut microbiome indicates that nutritional programming in tilapia culture can aid fish farmers.

Drs. Russell Borski, Scott Salger, and Courtney Deck, AquaFish IL researchers from North Carolina State University, teamed up with researchers from Bangladesh Agricultural University to investigate the potential for improving nutrient uptake efficiency in tilapia by restricting their dietary protein early in life. This technique, called "nutritional programming," conditions juvenile tilapia to absorb protein more efficiently, which can result in faster growth throughout their life cycle.

Key to the success of this approach are the millions of microorganisms that live in the fish's digestive tract, collectively known as the "gut flora." Just as in humans, the diversity of tilapia's gut flora is important to their overall health, and plays a role in how efficiently the fish can digest their food, which in turn affects how fast they grow. Fish that have more of the beneficial types of gut microbes digest nutrients better and have stronger immune systems.

This work was informed by previous USAID-funded CRSP research which found that tilapia fed on alternate days have a more balanced and diverse gut flora than the same fish that are fed every day. In order to determine whether nutritional conditioning affects the diversity of gut flora in tilapia, several groups of tilapia fry were grown in tanks, and fed either a low- or high-protein diet for 7, 14, or 21 days. After 60 days, researchers compared the lengths and weights of the fish, and analyzed the diversity of their gut microbes. Results showed that young tilapia given a protein-restricted diet for the first two

weeks of life, then fed a high-protein diet afterwards, grew larger and had a higher diversity of gut microbes than fish fed a normal-protein diet from the start.

The diversity of gut microbes was primarily affected by the length of time the fish consumed a particular diet, and not by the amount of protein in the diet. Future research should focus on identifying which microbes are most important for improved nutrient uptake in tilapia. This can pave the way for developing probiotic supplements that could improve growth rates and overall health of farmed tilapia.

For fish farmers in Bangladesh and beyond, this research means more than advancing scientific knowledge. It provides tangible ways to grow bigger fish while reducing operating costs, and helps put more money in farmers' pockets and more food on their plates.

UNLOCKING POTENTIALS OF AFRICAN LUNGFISH TO IMPROVE NUTRITION AND LIVELIHOODS IN UGANDA

by John Walakira, Kathryn Goetting, and Hillary Egna

The African lungfish (*Protopterus aethiopicus*) is an indigenous, air-breathing, freshwater fish that is endemic to the great lakes region of Kenya, Uganda, Democratic Republic of the Congo, Rwanda, and Tanzania. As a food fish, lungfish has high nutritional value and a desirable flesh quality that is preferred by many local people in Uganda and throughout East Africa.

Due to high demand, natural lungfish stocks are declining from overexploitation. Environmental degradation and the large-scale conversion of wetlands to agricultural land have imposed additional pressures on natural lungfish populations. Traditionally, fish farmers have collected young lungfish from the wild and raised them in small ponds. This practice is not environmentally sustainable and has resulted in low fish yields. Therefore, the development of sustainable lungfish aquaculture will help ensure a more reliable supply, better economic gains, and more efficient use of Uganda's natural resources.

Several earlier attempts to domesticate lungfish have been made, but have been met with little success. Further, attempts at captive breeding have not been well documented. Lungfish domestication is complex and requires an understanding of physiological and other characteristics that are not yet well understood, including spawning season, reproductive hormone profiles, egg quality and maturation, fecundity, size at sexual maturity, sex plasticity, and expected sex ratios of offspring.

AquaFish researchers examine a lungfish on-site in Uganda (Photo courtesy of John Walakira).

In collaboration with the National Fisheries Resources Research Institute (NAFIRRI) under the National Agriculture Research Organization (NARO) in Uganda, the AquaFish Innovation Lab has been working to develop culture technologies that will guide lungfish domestication in the East Africa region. Initial attempts to raise wild-caught lungfish fingerlings (~ 10g) revealed that they accept sinking pellets. This feeding method increased fish growth and survival rates increased to about 60%. These promising results provided key insights, considering that previous lungfish producers achieved survival rates of less than 15%.

The AquaFish IL team of scientists from NAFIRRI, Biosciences eastern and central Africa – International Livestock Research Institute (BecA-ILRI) in Kenya, Auburn University, North Carolina State University, and Oregon State University in the US have generated information that will inform lungfish breeders and conservationists. Reproductive studies have indicated that lungfish have an asynchronous female organ that ovulates 200-500 oocytes per spawn with seasonal peaks associated with rainfall periods. Studies investigating breeding methods showed that wild caught and ripe lungfish broodstocks are able to spawn in captivity if subjected to the synthetic hormones, human chorionic gonadotropin (HCG) and luteinizing hormone-releasing hormone (LHRH); and fertilized eggs will hatch optimally at 27-30 °C. Rearing and growth studies determined larvae weaned to artificial and live diets on the 16th day post hatch were most successful when the digestive system is fully developed. This study also found that if graded to the same size, lungfish fry grow well on a protein-rich (> 45%) commercial diet.

This novel research has built up the knowledge base for sustaining lungfish populations in Uganda and has provided a foundation for lungfish culture in East Africa. The development of sustainable lungfish aquaculture practices will contribute to national food security, reduce fishing pressures on wild lungfish

populations, and economically empower fishing communities and fish traders (especially women) who derive livelihoods from aquaculture products. Furthermore, information generated from this work will inform policies that will conserve lungfish biodiversity in East Africa.

FISH FARMING IMPROVES HOUSEHOLD NUTRITION AND FOOD SECURITY IN GHANA AND TANZANIA

by Lindsay Carroll, Caleb Price, Kwamena Quagrainie, and Hillary Egna

The African continent has abundant marine and freshwater fisheries resources, and yet some African nations have the lowest per-capita rate of fish consumption in the world. Fish can provide an affordable and nutritious source of protein for the rural poor, and can help improve dietary diversity, an important step towards achieving food security. Though many factors contribute to this disconnect (including the export of fish to foreign markets), rates of fish consumption in rural Africa are largely limited by access issues, such as high transportation costs, inefficient market distribution and infrastructure systems and availability issues, such as insufficient supply and lack of post-harvest storage systems.

Fish can provide micronutrients that are crucial for healthy functioning and development, especially in children. Dietary diversity is important to ensure nutritional completeness, and households that diversify their diet by consuming fish are more likely to be food secure than those that do not.

In the East African nation of Tanzania, poverty is widespread and food security is elusive for many of the nearly 50 million people who live there. Even though fish are widely available near production centers in coastal areas, remote inland populations have fewer options for purchasing and consuming fish products. In order to improve access to fish products in remote areas, there must be adequate infrastructure - namely, good roads and ample electricity for the delivery and storage of fish products.

Food security is also a pressing issue in the West African nation of Ghana, though the per capita consumption of fish for the average Ghanaian is about 25kg per annum, which is one of the highest in Sub-Saharan Africa. People living in the coastal regions of Ghana consume more fish than those in the inland regions due to availability in local markets. In some Ghanaian cultures, certain types of fish are considered taboo to consume.

In order to better understand the role of aquaculture in helping to address these challenges, researchers from the AquaFish Innovation Lab investigated the impact that access to fish and availability of fish products can have on food security in Ghana and Tanzania. Dr. Kwamena Quagrainie of Purdue University led a team of scientists from Kwame Nkrumah University of Science and Technology in Ghana and Sokoine University of Agriculture in Tanzania to identify the key determinants of fish consumption among rural, urban, and peri-urban households in these two African nations.

An AquaFish researcher surveys local Ghanaian women to determine their household's level of food security (Photo courtesy of Akua Akuffo).

In Tanzania, the AquaFish IL examined the impact of key infrastructure on seafood accessibility in rural, urban, and peri-urban households. In urban areas, access to transportation was a primary determinant for household accessibility to seafood. In recent years, the expansion of public transportation buses has increased access to seafood for peri-rural households by helping to reduce transportation costs and traffic congestion. Researchers also found that, in addition to good transportation networks, electricity and communication technologies were important to improving access to seafood through improving storage options for perishable fish products, pricing, and the availability of information for consumers.

In Ghana, diet diversity and seafood consumption were examined using the food consumption score (FCS), a measure of the nutritional quality of household diets and food security.

The study showed that fish-farming households are often more food secure and have more diverse diets than non-fish-farming households. Rural populations in Northern Ghana stood to benefit the most from implementing small-scale aquaculture operations, and women-led households in this region that start fish-farms had a 96% higher probability of achieving food security.

AquaFish IL findings from Ghana and Tanzania demonstrate the positive impact that small-scale aquaculture can have on food security and nutrition in rural households. Findings also emphasize the potential benefits for food security of investing in critical infrastructure, including electricity, communication networks, cold chains, and transportation.

APPENDIX B: AQUAFISH PUBLICATIONS

The following is a list of publications and peer-reviewed articles by AquaFish Innovation Lab (formerly AquaFish CRSP) investigators on their AquaFish-sponsored research. Some of the publications before 2009 may be attributable in part to the Aquaculture CRSP. For nearly two years, from 2006-2008, the Aquaculture CRSP overlapped with AquaFish CRSP.

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