FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Innovation Lab for Fish

Phase I Report October 1, 2018 – September 12, 2023

Cooperative Agreement 7200AA18CA0030

USAID
FROM THE AMERICAN PEOPLE

MISSISSIPPI STATE UNIVERSITY
GLOBAL CENTER FOR AQUATIC HEALTH AND FOOD SECURITY

Feed the Future Innovation Lab for Fish

Phase I Report October 1, 2018 – September 12, 2023

Cooperative Agreement 7200AA18CA0030

December 12, 2023

Prepared for:

Agreement Officer's Representative (AOR)

Feed the Future Innovation Lab for Fish (Fish Innovation Lab)

Bureau for Resilience, Environment, and Food Security (REFS)

United States Agency for International Development (USAID)

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Management Entity

The Feed the Future Innovation Lab for Fish (Fish Innovation Lab) is managed by Mississippi State University (MSU) and is housed in the MSU Global Center for Aquatic Health and Food Security, which is affiliated with the MSU College of Veterinary Medicine.

Members of the Management Entity

- Mark Lawrence, Director
- Stephen Reichley, Risk Mitigation Specialist, began as Deputy Director in September 2022
- Peter Allen, Productivity Frontier Specialist
- Jared Dees, Grants and Contracts Manager (through April 30, 2023)
- Alaina Dismukes, Communications Specialist
- Shauncey Hill, Program/Finance Manager (through March 31, 2023)
- Kathleen Ragsdale, Gender and Youth Equity Specialist
- Mary Read-Wahidi, Gender and Youth Equity Specialist
- Gina Rico Mendez, Human Outcomes Specialist and Monitoring, Evaluation, and Learning Specialist (as of January 31, 2023)
- Laura Zseleczky, Communications Manager

External Advisory Board

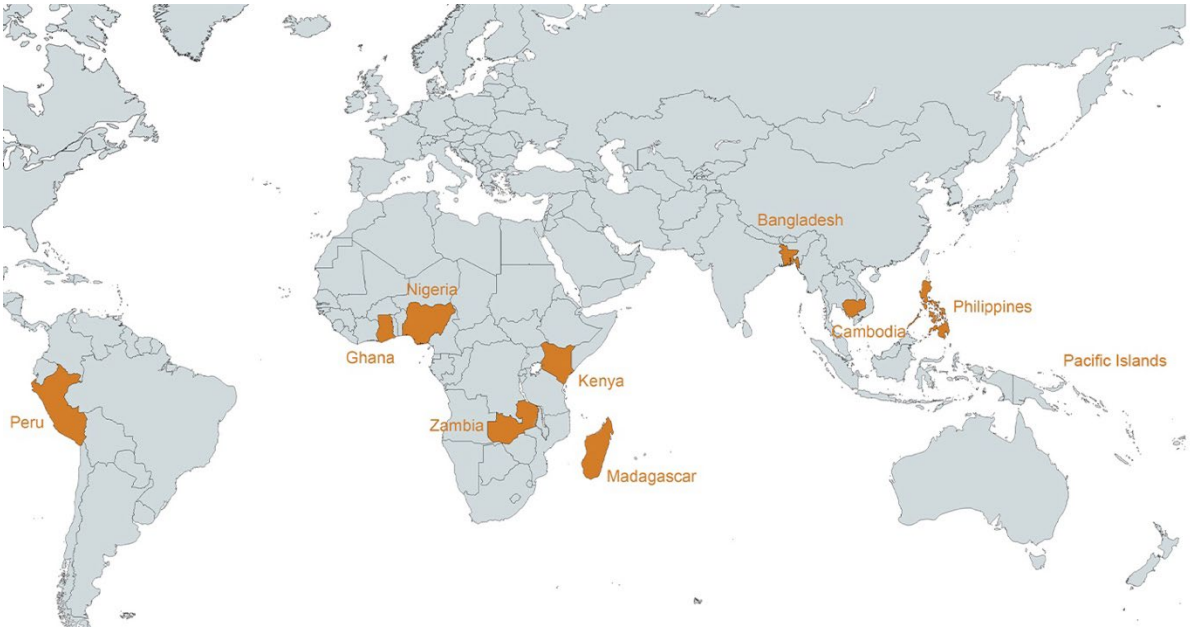
The Fish Innovation Lab Management Entity (ME) is advised by the Fish Innovation Lab External Advisory Board (EAB), which provides strategic direction for Fish Innovation Lab goals and objectives, gives scientific recommendations for Fish Innovation Lab activities, and monitors progress toward Fish Innovation Lab objectives.

Members of the External Advisory Board

- Michael Phillips, Director and Co-Founder of FUTUREFISH
- Melba B. Reantaso, Team Leader, Food Safety, Nutrition and Health, Food and Agriculture Organization of the United Nations (FAO)
- Rohana Subasinghe, Technical Lead, WorldFish Nigeria
- Elin Torell, Director of the Coastal Institute and Director of International Programs at the University of Rhode Island (URI) Coastal Resources Center
- Karen Veverica, Former Director, Auburn University E.W. Shell Fisheries Research Center

Countries Where the Fish Innovation Lab Works

Over five fiscal years from 2019–2023, the Fish Innovation Lab implemented five Quick Start activities and 18 research-for-development activities in Bangladesh, Cambodia, Ghana, Kenya, Nigeria, and Zambia, as well as a buy-in activity covering Madagascar, the Pacific Islands, Peru, and the Philippines (Figure 1).



Fish Innovation Lab Management Entity Partners

Research Triangle Institute International

- Rebecca Jeudin, Monitoring, Evaluation, and Learning Advisor
- Joanna Springer, Resilience Specialist

Texas State University

- Madan Dey, Asia Specialist

University of Rhode Island

- Austin Humphries, East Africa Specialist
- Karen Kent, West Africa Specialist
- Glenn Ricci, Capacity Development Specialist
- Elin Torell, Deputy Director and Human Outcomes Specialist through September 2022

Washington University in St. Louis

- Lora Iannotti, Nutrition Specialist

Regional Coordinators

- Md. Gulam Hussain, Asia Coordinator
- Sunil Siriwardena, West Africa Coordinator
- Andrew Wamukota, East Africa Coordinator

Abbreviations and Acronyms

AGGRC	Aquatic Germplasm and Genetic Resources Center
AMR	Antimicrobial Resistance
AOR	Agreement Officer's Representative
BAU	Bangladesh Agricultural University
BC	Bighead Catfish
BFRI	Bangladesh Fisheries Research Institute
BMP	Best Management Practice
BMU	Beach Management Unit
BSF	Black Soldier Fly
BSFL	Black Soldier Fly Larvae
CE SAIN	Center of Excellence on Sustainable Agricultural Intensification and Nutrition
ComFA+Fish	Complementary Food for Africa+Dried Fish Powder
DNA	Deoxyribonucleic Acid
DoF	Department of Fisheries
DWF	Distant Water Fleets
EAB	External Advisory Board
EH&S	Environmental Health and Safety
EMMP	Environmental Management and Mitigation Plan
ESBL	Extended Spectrum Beta Lactamase
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FGD	Focus Group Discussion
FY	Fiscal Year
G3	Generation 3
GRADA	Gender Responsive Agricultural Development Assessment
GRADA-FIL	Gender Responsive Aquaculture/Fisheries Development Assessment – Fish Innovation Lab
HC	Host Country
HI	Hazard Index
HICD	Human and Institutional Capacity Development
IACUC	Institutional Animal Care and Use Committee
IEE	Initial Environmental Examination
IITA	International Institute of Tropical Agriculture

IMC	Indian Major Carp
ITF	Insect-to-Fish
IYC	Infants & Young Children
LSME	Lean Subject Matter Expert
LSU AgCenter	Louisiana State University Agricultural Center
ME	Management Entity
MEL	Monitoring, Evaluation, and Learning
MSU	Mississippi State University
NGO	Nongovernmental Organization
NRDC	Natural Resource Development College
PCR	Polymerase Chain Reaction
PI	Principal Investigator
RUA	Royal University of Agriculture
SRA	Sequence Read Archive
SNP	Single Nucleotide Polymorphism
SOP	Standard Operating Procedure
TSU	Texas State University
UDUS	Usmanu Danfodiyo University, Sokoto
UI	University of Ibadan
UNZA	University of Zambia
UoC	University of Calabar
URI	University of Rhode Island
USAID	United States Agency for International Development
USG	United States Government
WCS	Wildlife Conservation Society
WUSTL	Washington University in St. Louis

Glossary

Aquaculture: “The farming of aquatic organisms, including fish, mollusks, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated” (FAO, 1988).

Small-Scale Fisheries: Also referred to as artisanal fisheries. Characteristics differ among countries, but the term generally means “traditional fisheries involving fishing households (as opposed to commercial companies), using a relatively small amount of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, mainly for local consumption” (FAO, 2014). “Women are significant participants in the sector, particularly in postharvest and processing activities. It is estimated that about 90% of all people directly dependent on capture fisheries work in the small-scale fisheries sector. As such, small-scale fisheries serve as an economic and social engine, providing food and nutrition security, employment and other multiplier effects to local economies while underpinning the livelihoods of riparian communities” (FAO, SSF Guidelines, 2015).

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Executive Summary

The Feed the Future Innovation Lab for Fish (Fish Innovation Lab) aims to alleviate poverty and improve nutrition in vulnerable populations through reliable and inclusive provision of fish, a nutrient-rich animal source food. Rich in both macro- and micronutrients, fish are among the most traded agricultural commodities in the world. In developing countries, more than 2.6 billion people depend on some form of fish for more than 20% of their total animal protein. How fish are produced, caught, processed, distributed, and sold therefore affects the nutrition and livelihoods of small-scale producers and vulnerable households, making equitable access to fish a vital part of the U.S. commitment to end global hunger and poverty. The Fish Innovation Lab supports and links research partners around the globe to identify, develop, and scale promising methodologies and technologies for local fish farming and sustainable fishing, and to intensify and diversify major production systems where the poor and undernourished are concentrated.

The Fish Innovation Lab began in September 2018 and has completed its first 5-year phase (Phase I). During this time, the Fish Innovation Lab implemented 23 research-for-development activities in Bangladesh, Cambodia, Ghana, Kenya, Nigeria, and Zambia, as well as a buy-in activity covering Madagascar, the Pacific Islands, Peru, and the Philippines. These activities were organized into three areas of inquiry: (1) improving productivity, (2) mitigating risk, and (3) improving human outcomes.

Fish Innovation Lab activities in advancing productivity (Area of Inquiry 1) focused on enhancing the productivity of aquaculture and fisheries systems to improve food security by not only ensuring more people can access fish as part of their diet, but also by driving income growth among people employed in the sector. Accomplishments included improving efficiency of aquaculture production, feed production, and fish processing in Nigeria through application of Lean management methods; implementing integrated rice-fish farming on private farms in rural communities in Nigeria; determining feasibility of fishmeal replacement in fish feed using black soldier fly larvae meal (Nigeria) and single-cell protein meal (Zambia); and supporting improved genetics of carp species in Bangladesh through family selection and sperm cryopreservation. Fisheries productivity was advanced using community-led fish landing monitoring activities in the Sre Ambel River in Cambodia and in coral reefs in southern Kenya, resulting in adoption of sustainable fisheries management practices by fishing communities.

The Fish Innovation Lab addressed reducing and mitigating risks (Area of Inquiry 2) through work to confront the many risks affecting the reliable supply of healthy fish and the livelihoods of those employed in aquaculture and fisheries. Accomplishments included determining fish pathogens impacting aquaculture in Nigeria and establishing a network of fish health veterinarians with support from fish diagnostic capacity at the University of Ibadan (UI); identifying major foodborne pathogens on fish and behaviors associated with fish contamination by processors in Dhaka City, Bangladesh; and characterizing pathogenic bacteria responsible for tilapia mortalities in Zambia for autogenous vaccine development.

Well-managed aquaculture and fisheries systems have the potential to improve nutrition and income, but more evidence is needed on how these systems can positively impact the lives and livelihoods of vulnerable groups. Human outcomes (Area of Inquiry 3) were addressed by using machine learning to identify aquaculture ponds from satellite imagery and producing extension videos in Bangladesh; developing low-literacy training for women fish processors in Nigeria to increase knowledge on nutritional value of fish and food safety; conducting nutrition training and sensory panels on complementary foods integrating fish powder in Zambia; using social marketing to increase mothers'/caregivers' use of fish in diets and increasing fishers' income from modified fishing gear in Kenya; identifying impacts of invasive crayfish on artisanal

freshwater fisheries in Zambia; analyzing economic implications of aquaculture value-chain development in Bangladesh to improve food security and market access for consumers and producers; and analyzing oyster samples harvested by women shellfishers for essential minerals to determine potential of oysters to reduce anemia prevalence in women of reproductive age in Ghana.

Through these activities, the Fish Innovation Lab developed technologies, practices, or approaches in the aquaculture and fisheries sectors that are now in different stages of development and uptake. In Fiscal Year (FY) 2023, 58 technologies, practices, and approaches were reported: 9 under plant and animal improvement research, 33 under production systems research, and 16 categorized as social science research. In FY 2023, Fish Innovation Lab activities had 1,641 individuals who participated in short-term trainings, 2,738 individuals who participated in U.S. government food security programs, 3,521 participants who applied technologies or practices, and 43 individuals who participated in long-term trainings.

The Fish Innovation Lab achieved impacts within four cross-cutting themes: capacity development, gender equity and youth engagement, nutrition, and resilience. *Capacity development* activities engaged U.S and host country teams, including both long-term training of graduate students in host countries and engagement of stakeholders, community members, and end users through short-term trainings and direct involvement in research activities. In Bangladesh, collaboration between the research teams and government entities raised the interest of government officials to explore avenues for implementation of innovations developed through the Fish Innovation Lab. To support *gender equity and youth access*, the Fish Innovation Lab led or participated in 25 gender/youth-related activities, and several research activities included specific gender equity goals. Research teams engaged youth in rice-fish farming capacity enhancement activities in Nigeria, which had 82% youth participation. In addition, fisheries monitoring training for community members in Kenya had 56% youth participation and 39% female participation. The Fish Innovation Lab promoted synergistic dissemination of *nutrition approaches and results*, including implementation of a social marketing campaign to increase consumption of fish by children in fishing families in Kenya and development and testing of recipes incorporating fish powder for complementary feeding of children in Zambia. The Fish Innovation Lab developed and launched online training in *resilience* and worked with seven research activities to develop more robust frameworks for resilience in their approaches.

In addition to the accomplishments of its research activities, the Fish Innovation Lab ME successfully facilitated the emergence of a community of practice around aquaculture and fisheries in Africa and Asia to promote strong cross-activity collaborations and shared learning. This was accomplished through implementation of a Learning Agenda that included quarterly virtual learning sessions, Fish Innovation Lab Annual Meetings, and in-person Aquaculture Sector meetings in Bangladesh and Nigeria. Some tangible results from this community practice included a Fish Innovation Lab-led virtual side event at the 2021 Norman E. Borlaug International Dialogue, dedicated Fish Innovation Lab sessions at the 2022 World Aquaculture Society (WAS) meeting in Singapore and 2023 Aquaculture America conference in New Orleans, and a panel at the American Public Health Association (APHA) 2022 Annual Meeting.

In summary, the Fish Innovation Lab made significant achievements in research and end-user adoption of improved technologies, practices, or approaches to support development of aquaculture and sustainable fisheries in Feed the Future countries in Africa and Asia. By leveraging the community of practice that has been developed, the Fish Innovation Lab is well positioned to scale these promising technologies and develop new innovations to achieve its long-term goals of improved diet quality in vulnerable groups through increased consumption of safe aquatic foods and poverty alleviation in aquatic food systems.

Focus Country Key Accomplishments from Phase 1

In Phase 1, the Fish Innovation Lab implemented activities in West Africa (Ghana and Nigeria), Eastern and Southern Africa (Kenya and Zambia), and Asia (Bangladesh and Cambodia). After the completion of the Quick Start activities in FY20, the Fish Innovation Lab implemented 13 activities awarded competitively in FY20 and five direct commissioned activities awarded in FY21. This section presents the accomplishments of competitively selected activities and direct commissioned activities, which remained active in FY23. The list of activities funded through the Fish Innovation Lab is shown in Appendix 1.

1. **Bangladesh:** The Fish Innovation Lab had five research activities in Bangladesh. The *Carp Genetic Improvement* activity disseminated Generation 3 (G3) rohu carp to thirteen commercial hatcheries, which produced 2,826 kg of G3 rohu spawn that are expected to be used by 42,390 farmers in 2023. The team anticipates that G3 rohu spawn production will increase as demand increases for the G3 rohu multiplier seed. Using on-farm growth performance trials, G3 rohu were found to have 37% improved growth rate, on average, compared to unimproved controls. The *Cryogenic Sperm Banking* activity developed methods for cryopreservation of sperm from six carp species, implemented a cryogenic sperm bank for these six species at Bangladesh Agricultural University (BAU), and bred all six species using cryopreserved sperm in four regions, resulting in 28 hatcheries successfully producing seeds. Cryopreserved-sperm-originated seeds reared for brood production demonstrated a significantly higher growth rate than control (industry standard) seeds in all six species due to introducing quality germplasm through cryopreserved sperm. The *Foodborne Pathogens* activity conducted risk modeling based on detection of foodborne pathogens from samples collected from the fish supply chain. Results showed that 92% of cut-fish samples from retail markets in Dhaka City were contaminated with *E. coli*, which was significantly higher in wet-market samples (97%) compared to super shops (71%). Fish cutting boards were most frequently contaminated, indicating that an intervention at the cut-up tables in retail markets could reduce pathogen loads in ready-to-deliver fish to consumers. The *Market Analysis* activity performed analysis of the National Income Expenditure Survey Data from 2000 to 2016, revealing that fish consumption increased over the period for every category of household. The lowest income quantile had the fastest growth in fish consumption. The findings indicated that aquaculture is contributing to changing fish consumption patterns irrespective of income groups and the residential status of households. Analysis of trade credit indicated that it enabled farms to access improved production technology with a positive trade-off between benefits and costs. Analyses found that Bangladesh's shrimp export competitiveness has dipped marginally in recent years despite continuous growth in competitor countries. The *Harnessing Machine Learning* activity developed a novel methodology for determining accurate estimates on aquaculture pond area and types of production. To support planning and investment decisions, the team determined contributions to employment on- and off-farm (by gender) and contributions to regional economies. A method was developed for estimating the nutrient productivity of aquaculture, and short, low-cost extension videos were used to disseminate knowledge on aquaculture technologies via social media to reach large audiences and accelerate the rate of aquaculture technology adoption.

    - **Local Capacity Strengthening:** The *Carp Genetic Improvement t*eam conducted hatchery training workshops on the management and marketing of genetically improved carp. Participants received a manual of the presented slides translated into Bangla and available online. The *Cryogenic Sperm Banking* team conducted fourteen training workshops on dissemination of cryopreservation technology for more than 550 stakeholders (hatchery and nursery operators, fish farmers, scientists, government officers, and nongovernmental organizations or NGOs), junior faculty members, and graduate students. Training materials and video documentaries were developed and can be used to train future stakeholders. The

team members participated in a 2-week-long advanced training through the Aquatic Germplasm and Genetic Resources Center (AGGRC) and Louisiana State University Agricultural Center (LSU AgCenter). The *Foodborne Pathogens* team held a comprehensive day-long training workshop in collaboration with the Bangladesh Food Safety Authority on "Risk Analysis in the Regulatory Process," which enhanced the skills and knowledge of food safety officers in conducting microbial risk assessments. The Department of Fisheries (DoF) applied training to respond to consumer demand for genetic detection of major foodborne pathogens for the first time. The *Market Analysis* activity presented comprehensive findings (covering the last 23 years) of fish consumption at their final policy workshop in July 2023. The Bangladesh Minister of Planning and more than 170 researchers, industry representatives, farmers, and policymakers made valuable contributions on discussion of policies for both governmental entities and industry personnel. Young farmers, including women, and young scientists from government departments, institutes, and five universities attended the session and benefited from it. The *Harnessing Machine Learning* team delivered three workshops on machine learning for 147 government, non-profit, and private sector participants, one of which was held at the DoF headquarters at the invitation of the Director General, with attendees including 33 senior fisheries officials.

- **Gender Equality:** By collecting very detailed data on women's, men's, and youth employment by activity and labor source (family, casual, and permanent) in five segments of the aquaculture value chain, the *Harnessing Machine Learning* activity developed possibly the most detailed picture of gendered employment in aquaculture value chains ever completed. The activity also utilized a version of the Women's Empowerment in Agriculture Index in its farm survey, modified to fit the context of aquaculture in Bangladesh.
- **Youth Engagement:** In the *Cryogenic Sperm Banking* training workshops arranged for hatchery and nursery operators and fish farmers in Mymensingh, Jashore, Faridpur, and Barisal regions, at least 30% of attendees were female and youth. Almost all of the activity's junior faculty members and students were youth, and more than 30% were female. In the *Foodborne Pathogens* activity, the team collected fish and environmental samples from three major stages of the fish supply chain, including primary producers of pangas and tilapia in different districts of Bangladesh, wholesalers, and retail sellers in Dhaka City. The team could not find any female actors along the supply chain, except one female farmer at the primary production level. However, a notable proportion of actors were young. Of all retail and wholesale vendors and farmers included in the study for interview and sample collection, 42% were young, with a majority (90%) from retail and wholesale markets. At the "Risk Analysis in the Regulatory Process" workshop, approximately 25% of the trainees were female, promoting gender diversity in the food safety domain. A substantial number of the participants (68%) were below the age of 35, reflecting the engagement of young professionals in this field and the importance of targeting this demographic for the sustainability of training outcomes.
- **Private Sector Engagement:** By the end of the *Carp Genetic Improvement* activity, approximately 3,017 farmers were supplied with fish for grow-out from the 254 kg of spawn sold in 2022. Production of 2,826 kg of G3 rohu spawn by 13 hatcheries (including private sector hatcheries) in early FY23 is expected to supply 42,390 farmers in 2023. G3 rohu spawn sale prices documented by private hatcheries in 2022 were more than double the price of unimproved spawn and help drive increased spawn production while performance of the seed drives demand.
- **Digital Engagement:** The *Harnessing Machine Learning* team delivered a six-part online

training course on remote sensing for fishpond identification and machine learning methods with live, interactive feedback sessions reaching 136 participants (22% female and 68% from Bangladesh) and produced 13 videos on innovative practices in aquaculture reaching 10,107 users on Facebook and YouTube. Following the final Harnessing Machine Learning activity workshop, the DoF website tagged the activity's online interactive aquaculture database as a decision-making platform/tool on its homepage navigation bar (see "Online Fisheries Statistics" at http://www.fisheries.gov.bd).

- **Climate Change and Climate Finance:** Results from the *Carp Genetic Improvement* activity are consistent with genetic gains of 10% per generation for growth rate. These findings demonstrate that genetically improved carp produced using this activity's methods have the potential to substantially enhance pond productivity, farmer incomes, and the supply of animal protein in Bangladesh. The *Market Analysis* team's survey data on the effects of COVID-19 demonstrated how various stakeholders, including producers, traders, fishers, and consumers, addressed the challenges encountered during the pandemic. The team presented and published the findings to inform future policy initiatives aimed at enhancing the resilience of aquaculture, fisheries, and vulnerable populations in the face of similar natural shocks. Climate-smart aquaculture techniques in coastal areas such as shrimp and prawn farming, sustainable fish feed practices, and the use of prebiotics and probiotics were discussed to reduce environmental risks. Policies for vulnerable communities were proposed to minimize the impact of natural disasters on fishery livelihoods.

In-Country Partner Organizations: BAU; WorldFish, Bangladesh & South Asia Office; International Centre for Diarrhoeal Disease Research (icddr,b); Patuakhali Science and Technology University; Bangladesh Fisheries Research Institute (BFRI).

2. **Cambodia:** The Fish Innovation Lab had two research activities in Cambodia. Research by the *Bighead Catfish* activity evaluated the impact of commercially available aquafeed on growth performance of bighead catfish (BC). The result showed that feed brands did not significantly affect fish growth, FCR, or somatic index. However, feed with 35% protein level improved growth performance and FCR of BC, indicating that 35% protein level promoted BC culture in a pond net-cage system. The *Cambodian Fisheries and Food Processing* activity collected accurate data over two years on the status of the Sre-Ambel River fishery, creating baseline information on harvested species, yield per effort, size distribution, fishing gear selectivity, fishing zones, and distance traveled. During the assessment, 162 species were recorded, represented by 118,528 fish with 48,048 individual-level data entries and photos for species and length verification. Data is accessible online on the iFISH data analysis and visualization platform (https://ifish.shinyapps.io/ifish). Crucial information on fish size and nutritional composition is now available for targeted harvesting approaches and preservation methods. Data showed that many fish species are potentially being harvested at sizes that do not allow reproduction. Regulations to set minimum harvest sizes and/or gear restrictions to reduce non-selective catch (allowing smaller fish to escape) should be considered. The activity also sought to improve fish protein shelf life by providing education on fish preservation techniques and conducting nutrient analyses of primary harvested species. Buffered vinegar was identified as a promising inexpensive preservation approach because it does not affect sensory attributes and was effective. A smoking method and device (smoking tunnel) was identified that fishermen can easily build; this method has potential to add value to fish products and enables safe fish consumption in Cambodian households.

    - **Local Capacity Strengthening:** To improve the formulation of sustainable feeds for BC, the *Bighead Catfish* team established three aquaculture facilities at the Royal University

of Agriculture (RUA) Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN) and trained operators to support feed production for research and teaching. These were (i) a wet lab with forty 150-L aquaria with a recirculating aquaculture system and flow-through system; (ii) a cage system in a pond with a set of 16 cages; and (iii) a fish feed pelletizing machine, including an extruder, mixer, and grinder. The activity strengthened partnerships by providing broodstocks of BC for teaching, research, and hatching purposes; engaging in training activities; and hosting a visit by various stakeholders to learn about the wet lab's activities. The capacity built over the life of this activity equipped RUA personnel and students in their aquaculture nutrition research, which will benefit Cambodian aquaculture as whole as the industry grows. The *Cambodian Fisheries and Food Processing* activity empowered fisheries communities on the Sre Ambel River by improving capacity of fisher communities to monitor fisheries resources through development and implementation of the Fisheries Harvest and Recovery Monitoring Protocol and the Community Fisheries Assessment Tool: iFISH App.

- **Youth Engagement:** Nutrition trainings by the *Cambodian Fisheries and Food Processing* activity were designed to have a strong focus on resilience of value chains and households by training participants on potential income-generating microenterprise opportunities for women and youth entrepreneurs.
- **Digital Engagement:** From the *Cambodian Fisheries and Food Processing* activity, two years of harvest data on the Sre-Ambel River fishery was uploaded and is available on the iFISH app and data visualization platform (https://ifish.shinyapps.io/ifish). Each community fisheries organization council received a Fish Innovation Lab-funded smartphone (built-in with a smart application) to assist them with monthly smart patrols to reduce illegal fishing activities. The Cambodian Wildlife Conservation Society (WCS) posted about the smart patrols on Facebook to encourage local community members to participate in conservation. A collection of video clips on fish processing methods such as smoking, nutritional sampling and preparation methods, and sensory techniques is available for further training beyond the grant period.
- **Climate Change and Climate Finance:** The *Cambodian Fisheries and Food Processing* activity trained fishers and established a citizen science fishery harvest data collection program. Capacity was developed in Sre Ambel community fisheries organization members to better manage fisheries and enhance community resilience in the face of changing climate conditions. The tools and knowledge provided to fishermen through research and workshops will enable them to better preserve fish and add more nutritional and economic value to fish products to limit climate impacts on the fishery.

In-Country Partner Organizations: WCS, Phnom Penh, Cambodia; Sre Ambel Community Fisheries Council; CE SAIN, RUA.

3. **Ghana:** The Fish Innovation Lab had one activity in Ghana, *Micronutrient Impact of Oysters*, which aimed to investigate the contribution of oyster consumption to iron and zinc intakes of women shellfishers in three estuary sites. The activity also assessed whether heavy metal contamination of oysters is a health concern. Only 12.5% of the women shellfishers reported consuming any oysters in 24-hour dietary recalls. Approximately 92% of women were identified to have some form of household food insecurity, and severe food insecurity ranged from 72% to 85%. A total of 20% of the women had anemia, and only 21% achieved dietary diversity. Analysis was performed on 915 oyster samples from three sites in Ghana for 17 minerals and heavy metals, including macro minerals (e.g., calcium, magnesium, phosphorus, potassium, sodium), trace minerals (e.g., chromium, cobalt, copper, iron, manganese, nickel, selenium, and

zinc), and heavy metals (e.g., cadmium, mercury, and lead). Analysis determined that compared to eastern oysters in the U.S., oysters in Ghana were much higher in iron (126 mg/kg compared to 46 mg/kg). The mean Hazard Index (HI) for arsenic, cadmium, lead, and mercury from oyster consumption among the women shellfishers was low, suggesting no potential health effects of the metals. Promoting oyster consumption may be a promising strategy to improve nutrient intakes and prevent anemia in estuarine communities.

- **Local Capacity Strengthening:** Research results provided authorities, decision-makers, and women shellfishers with the information necessary to spur action to enhance the sustainability of oyster production and promote oyster consumption to improve dietary nutrition. This activity supported the dissertation research of Mr. Francis Z. Taabia, a Ph.D. nutrition candidate in the University of Ghana Department of Nutrition and Food Science.
- **Gender Equality:** There is a research gap on the nutrition of women shellfishers in Ghana. This research activity measured anemia, which disproportionately affects women. The activity also studied women's dietary intake to determine how oysters may be part of the solution to reduce anemia by providing iron to their diet. By confirming there is no heavy metal contamination of concern in oysters, the research established a foundation that can be used to promote oysters to address nutritional deficiencies. The findings can benefit women's health and livelihoods by showing that shellfishing, a woman-dominated activity, can provide essential dietary minerals.

In-Country Partner Organizations: University of Ghana.

4. **Kenya:** The Fish Innovation Lab had two activities in Kenya. The *Samaki Salama* activity implemented selective fishing gear (gated traps), which resulted in 10% higher yields with fewer juveniles, resulting in 13% increase in fish value. Fishers who received a bundled treatment of gated traps and social marketing about nutritional value of fish took home significantly more fish (12% of catch) than those who did not (7% of catch). The intervention, including the nutrition social marketing campaign, significantly increased child growth in height, child fish consumption, and child dietary diversity. The *Coral Reef Fishery Sustainability* activity found that fishing community members were more effective at measuring catch than equally trained government staff, which might be attributed to residing within the community and their commitment to the monitoring program. Dependent stock assessments indicated that all fisheries were overexploited except for the national marine reserve. Yields declined with distance from the park and reserve, with many fisheries underperforming by 1–2 tons/km^2 per year. Due to training provided by the team, fisher community acceptance of nearly all governance institutions and fisheries restrictions improved significantly by the end of the study. The largest changes in community attitudes were related to some of the more contentious restrictions, such as closures and species restrictions.

    - **Local Capacity Strengthening:** The *Samaki Salama* activity educated fishermen on sustainable fishing practices, and caregivers were trained on appropriate child-feeding practices. The caregivers received three follow-up visits to encourage them to continue practicing what they had learned. Community health volunteers, a cornerstone of Kenya's health care system, were trained and provided teaching aids on appropriate child-feeding practices, care-seeking practices, and hygiene and sanitation. They were also provided learning materials on how to conduct home visits, assess the health and nutritional status of children, and offer more nutrition education support to caregivers with challenges. The community health volunteers also learned appropriate cooking methods and how to conduct cooking demonstrations. The *Coral Reef Fishery Sustainability* activity trained fish data collectors and other beach management unit (BMU) officials on sustainable fishing practices

and collecting fish catch data, and the activity supplied them with equipment such as portable weighing scales and tape measures. Trainings on WCS data collection protocols, use of mobile phones in data collection, and the Kobo Collect app (used for data entry and coding) were conducted for fishers in 12 BMUs, as well as individuals from Kenya Wildlife Service, county fisheries, Kenya Marine Fisheries and Research Institute, the National Youth Service, and the local security authority within the Vanga-Shimoni seascape. Participatory mapping enabled 90 BMU members and county fisheries officers to gain knowledge and skills to produce and validate hand-drawn and digitized maps of fishing ground landmarks and fishing zones. The exercise led to the realization that some fishermen were still fishing within the Locally Managed Marine Areas or Marine Protected Areas. Forty-five individuals from five communities were trained to identify fish species and evaluate fish biomass in eight sites within the Vanga-Shimoni seascape area. The activity produced films of underwater surveys and participant interviews. A fish biomass training manual was developed in English and Swahili to support sustained and scaled-up capacity for these activities.

- **Gender Equality:** The *Samaki Salama* activity included female and male caregivers who were involved with the care of young children (both male and female). The *Coral Reef Fishery Sustainability* activity post-intervention household surveys found women had increased their support for fisheries management restrictions more than men. The surveys created an opportunity to capture opinions of men and women of different age groups and within communities involved, despite the cultural treatment of men as the heads of the households. Women had access to family- and community-level information, including aquatic resources. Some demographic questions were areas of research best addressed by women, including household sizes, fortnight expenditures, other household occupations, frequency of fish consumption, and reasons why households were consuming less fish. Disaggregated analysis of management preferences and governance principles provided information on women and youth involvement and contribution in governance issues like decision-making and benefit sharing.
- **Youth Engagement:** Fifty-one percent of the 45 fish biomass trainees in the *Coral Reef Fishery Sustainability* activity were youth.
- **Digital Engagement**: The *Coral Reef Fishery Sustainability* activity used mobile apps Atlan Collect and Kobo Collect, which enabled community data collectors and county fisheries officers to monitor fish landings by recording fish landed by family and fishing effort. The use of these mobile apps increased awareness, informed stakeholders on reef status and community capacity, and allowed recommendations to relevant governance bodies.
- **Climate Change and Climate Finance:** According to data collected from some of the *Samaki Salama* activity sites, household incomes improved, and households were able to diversify their sources of income because of increased catch from gated traps aimed at allowing juvenile fish to escape. This is likely to help manage shocks and stresses in artisanal fishery operations, buffering fishers during low fishing seasons, contributing to improving fish stock status in areas impacted by climate change, and improving adaptive capacity. The *Coral Reef Fishery Sustainability* activity determined that established yields in Shimoni-Vanga were half as low as fringing reefs. However, fishing reefs around marine reserves and parks in this seascape recorded higher yields that decline with distance from the reserves and parks. Areas with community closures recorded higher yields, implying that high fishing effort is the main hindrance in achieving recommended yield levels. Marine protected areas (community and government) are resilient because of enforcement, and reefs within and outside the protected areas have

similarities, showing the general resilience of the seascape to climate disturbances. The Coral Reef Fishery Sustainability activity informed managers and resource users of the state of fisheries resources. As a result, communities took initiatives to amend by-laws that govern fishing areas, such as setting targets to achieve a fishing effort of four to seven fishers per square kilometer. Patrols by local communities and national government partners to root out illegal activities increased. Community members were more willing to learn and practice fish catch monitoring to inform resource status and as an employment opportunity.

In-Country Partner Organizations: Pwani University, Egerton University, WCS, Kenya Marine and Fisheries Research Institute.

5. **Nigeria:** The Fish Innovation Lab had five activities in Nigeria. Through the *Aquaculture Diversity in Rural Communities* activity, more than 700 farmers learned how to adapt rice fields to integrate fish culture using technological packages developed through the Fish Innovation Lab. The activity found that rice-fish farming increased biodiversity due to reduced chemical use, and profitability increased compared to rice monocropping. The *Farming Insects in Nigeria* activity found profitability of catfish farming was nearly 20% higher in feed trials of catfish fed with a black soldier fly larvae (BSFL) component compared to conventional feed, and there was no significant difference in fish weights. Aquaculture value-chain efficiency showed significant improvements due to interventions implemented through the *Lean Production Systems* activity. Farmers reaped benefits from Lean training regardless of age, gender, geographical location, company status, farm type, farm size, and annual income based on analysis of 265 interventions on 213 fish farms in two states. The *Improving Biosecurity* activity analyzed 399 fish samples collected from farms in Delta and Ogun states to identify pathogens of concern causing disease in Nigerian catfish aquaculture, and epidemiological analyses of the resulting data identified several risk factors and biosecurity gaps in local production systems. A Best Management Practices (BMPs) manual for catfish farmers and the E-AquaHealth Network digital platform helped bridge the gap between fish farmers and aquatic veterinary professionals to enhance quality service delivery and improve fish health. Training and low-literacy customer outreach tools developed by the *Nourishing Nations* activity enabled fish processors to grow their businesses, increase market share, and diversify product lines. Cost-per-nutrient guidelines were produced for locally available fish based on lab analysis of nutrient content, contaminant detection, and market data; the guidelines will aid in the design of nutrition-sensitive programs and policies.

    - **Local Capacity Strengthening:** Institutional demonstration farms for rice-fish farming were established by the *Aquaculture Diversity in Rural Communities* activity at Usmanu Danfodiyo University, Sokoto (UDUS), and UI enabled continuous student training and increased capacity to support and scale the technology. Faculty and staff from UDUS and Michael Okapara University of Agriculture Umudike were trained in fish-seed production along with farmers and hatchery operators from Kebbi and Ebonyi States, which further increased capacity to support farm diversification technologies. Experiments on BSFL meal production by the *Farming Insects in Nigeria* activity strengthened local capacity at UI. Capacity was developed in public-sector personnel from agriculture and fisheries in Ebonyi, Cross-River, and Oyo States to train farmers in BSFL production technology. Two cooperatives benefited from the BSF activity and can facilitate scale up: Treasure Fish Farmers Multi-Purpose Cooperative Society and Ijebu Development Initiative on Poverty Reduction. Through the *Lean Production Systems* activity, 40 Nigerian aquaculture value-chain actors were trained and certified as Lean Subject Matter Experts (LSMEs) in aquaculture. They were equipped with the necessary tools to train others to adopt and disseminate the Lean management tools, resulting in

265 individuals in two states who were trained and equipped to use Lean management tools in aquaculture. Biosecurity trainings and events by the *Improving Biosecurity* activity contributed to improving participant and stakeholder capacity, including fish farmer associations, extension experts, private-sector aquaculture value-chain actors, government ministries and departments, academia, and research institutions. Trainings developed capacity to understand and manage aquatic animal diseases and implement biosecurity in aquatic food systems. This capacity contributes to reducing disease-related losses and therefore improving access to more nutritious aquatic foods.

- **Gender Equality:** Of the 727 rice-fish activity beneficiaries in the *Aquaculture Diversity in Rural Communities* activity, 32% were women, and 7% were youth. Among the 265 overall participants in the *Lean Production Systems* activity, 20% were women, 10% were under 31 years old, and 44% were between 31–43 years old. Data showed that both women and men were good adopters of Lean management, and that women could help scale the technology. The percentages of women were modest but represent efforts to ensure women are among the innovators who can apply and disseminate production technologies in the male-dominated aquaculture sector. In the *Nourishing Nations* activity, women made up 72% of participants trained on fish processing techniques and business skills to strengthen capacity as strong economic actors in the fish-processing sector. Processors strengthened their technical skills in producing high-quality, safe, and nutritious processed fish products for local consumption and strengthened their business skills in marketing their products. Many planned to use the knowledge and practical experience gained to develop business plans to enhance productivity and expand their businesses. Women and youth fish processors in Delta State began organizing into business cooperatives with support from training facilitators and activity team members because of the training they received. Women and youth fish processors reported frequent use of the low-literacy tools developed by the activity for educating customers and the general public on the benefits of fish consumption for human nutrition. The tools also increased knowledge among women fish processors about proper nutrition, empowering their decision-making ability, particularly in relation to their business practices.
- **Youth Engagement:** Aquaculture in Nigeria is often considered an activity of retirees. The *Lean Production Systems* activity targeted younger individuals to focus on a professional orientation to aquaculture as a business that could be a source of income. Only 10% of the 265 beneficiaries were over 57 years old. Most (44%) were between 31–43 years old. The *Farming Insects in Nigeria* activity initially targeted women and youth catfish farmers for recruitment. This effort proved to be effective in attracting youth, as 72% of project participants were aged 15–29 years. The *Aquaculture Diversification in Rural Communities* team conducted a series of trainings on value addition, especially on fish smoking using modern smoking kilns. These trainings shared knowledge on how modern methods to preserve fish can significantly reduce postharvest losses, thus helping to improve livelihoods through robust market opportunities for the products. Almost 60% of the trainees were youth and women.
- **Private Sector Engagement:** The work led by the *Improving Biosecurity* activity contributed to private sector engagement, such as private organizations within the catfish aquaculture value chain, financial institutions from Ogun and Delta States, and private-sector veterinarians through the association of veterinarians and para-veterinarians. These actors participated in the stakeholder engagement meeting on "Implementation of Better Management Practices in Aquaculture and E-Technology Platform Adoption for Sustainable Aquaculture Development in Nigeria" in Ibadan, while

trainings such as the “Molecular Training Program” in Penang and Kuala Lumpur, Malaysia, and virology training at MSU in the U.S. significantly contributed to private sector buy-in for the future of biosecurity policy-making efforts for Nigeria.

- **Digital Engagement:** The *Improving Biosecurity* activity developed an E-Aqua Health diagnostic extension platform (https://ohrg-unibadan.org/aquahealth), which is hosted by UI. The platform is used by farm cluster leaders, resident veterinarians, and UI researchers to enhance prompt response to disease outbreaks and support fish farmers.
- **Climate Change and Climate Finance:** Rice-fish farmers were trained by the *Aquaculture Diversification in Rural Communities* activity on how to use local Nigerian Meteorological Agency weather reports and climate information in decision-making on the timing of crop planting. The activity team relied on the area wetland mapping they developed in decision-making on establishment of rice-fish farming outside of flood-prone locations. Integrated rice-fish farming provided protection against one crop failure. The agroecological approach to rice-fish farming also promoted the use of organic manure to build the primary production of natural fish food within the rice field. Consequently, farmers spend less money on chemical fertilizer, herbicides, and pesticides. The rice-fish system provides direct sources of fish and other aquatic foods found in rice fields (crabs, insects, reptiles) and allows the farmer to harvest fish for home consumption intermittently, leaving the rest for future consumption. The *Lean Production Systems* study demonstrated that Lean management tools are simple to incorporate and effective. Building a more resilient aquaculture industry in Nigeria requires equipping farmers with the tools to address different types of on-farm waste. Activities by the *Improving Biosecurity* activity to reduce fish disease impacts contributed to resilience at the community, system, national, and regional levels by using a cluster management approach to reduce disease exposure. The activity also addressed antimicrobial resistance (AMR) by encouraging reduced antibiotic use and contributed to an improved regulatory environment.

In-Country Partner Organizations: University of Ibadan; WorldFish; University of Calabar (UoC); International Institute of Tropical Agriculture (IITA); Usmanu Danfodiyo University, Sokoto; and Michael Okapara University of Agriculture Umudike.

6. **Zambia:** The Fish Innovation Lab had three activities in Zambia. The *Vaccines for Tilapia* activity developed autogenous fish vaccines from two bacterial pathogens identified from sick fish. Both vaccines provided good or some protection using the injection exposure route. The more effective vaccine from *Lactococcus garviae* showed promising initial trends in farm field trials. The study demonstrated that vaccination against localized disease pressures can be an effective part of an aquatic animal health program for the country. Studies by the *FishFirst! Zambia* activity supported the conclusion that improving the diets of vulnerable infants and young children is achievable by incorporating locally available nutrient-dense pelagic small fish in daily meals. Research by the *Zambia Crayfish* activity documented that invasive crayfish populations were robust with multiple age classes present. The crayfish appeared in seven previously unreported locations in the Zambezi River Basin, including in the Kwando sub-watershed of the Zambezi Basin in the Western Province that borders with Angola, which has a seasonal aquatic connection to the critical Okavango Delta Wildlife Refuge in Botswana. These robust datasets were transmitted to the Zambian Fisheries and Environmental Conservation Departments and should aid in policymaking to avoid spread to the Northern and Eastern Regions of the country. Negative impacts of crayfish included damage to fishing gear and fish, making fish inedible and requiring disposal, and causing fishers to fish longer to make up for discarded fish, affecting fishers’ livelihoods.

- **Local Capacity Strengthening:** The *Zambia Crayfish* activity increased capacity in application of the Electronic Length Frequency Analysis technique for the analysis of crayfish populations in Zambia. The research activity's long-term trainee, Chibwe Katapa, is successfully using Electronic Length Frequency Analysis as a central part of her master's thesis. Her use of this technique has been a relatively novel approach for Zambian fisheries professionals. Given this capacity, there is increased potential to spread the use of this powerful contemporary fisheries stock analysis technique to other fishery species beyond crayfish in Zambian waters. This trainee can be an asset for both the Zambia DoF and for colleagues at the University of Zambia (UNZA). The final meeting and the reports of the Zambia Crayfish activity informed Zambian aquaculture and fisheries professionals of the spread of the crayfish, its adaptation to Zambian waters, and its impact on fishers and their perceptions and use of crayfish. The *FishFirst! Zambia* activity trained cohorts of 38–66 participants on fish and nutrition as well as microenterprise and entrepreneurship. Trainees included mothers, Community Health Volunteers, entrepreneurs and businesses, and government officials recruited from the districts of Gwembe, Siavonga, and Sinazongwe,. These participants also took part in sensory panels and learning events related to food products and recipes enhanced with dried fish powder. The *Vaccines for Tilapia* research team trained staff from Copperbelt University in Zambia on techniques used in disease diagnosis. A Copperbelt University master's degree student was introduced to molecular techniques such as polymerase chain reaction (PCR) methods, sequencing, and basic local alignment search tools for identifying microorganisms. Ministry of Fisheries and Livestock staff benefitted from training on fish sample collection from the field, sample packaging for transportation to the laboratory, and preservation. Six staff were trained in these activities, two of whom were female. The study empowered local fish farmers with aquatic biosecurity knowledge and the possible use of vaccines in fish disease control.
- **Gender Equality:** The *Zambia Crayfish* team conducted focus group discussions in four locations, two in Lake Kariba and two in Kafue. The use of focus groups in addition to a survey and polling questionnaires for fishers allowed for targeted queries to women and youth stakeholders. Women play a key role in the utilization of crayfish; they are responsible for some marketing of crayfish and have an important role in preparing meals with crayfish in the home. An unexpected finding was that some entrepreneurial women crayfish marketers occasionally employ men to fish for crayfish to increase the amount of crayfish for the women to sell. The *FishFirst! Zambia* activity focused on improving nutrition among vulnerable households, particularly for rural women of reproductive age and infants and young children (6–23 months). By furthering knowledge of nutritional benefits of dried fish powder and developing/testing Complementary Food for Africa+Dried Fish Powder (ComFA+Fish) products/recipes for these groups, the activity improved gender equity in nutrition. By promoting the inclusion of women/youth entrepreneurs in ComFA+Fish scale-up, the activity improved gender and youth equity in and resilience of fish value chains and households. The *Vaccines for Tilapia* team trained a female graduate student and retained all eight of the women farmers participating in the fish vaccine study (24% of participating farmers) for the activity's engagement with farmers to improve knowledge on aquatic biosecurity and fish health.
- **Youth Engagement:** The *Zambia Crayfish* activity focus group discussions involved many youth, particularly in Itezhi-tezhi. These were trappers who moved from Kafue Gorge in search of more and larger-sized crayfish. At the same time, the Itezhi-tezhi youth were mostly involved in kapenta (small pelagic fish) fishing and, like women, faced negative impacts from crayfish via damage to gear and catch as they mostly set their

nets in shallow waters. They expressed interest in learning about how they could utilize crayfish in different ways. The *FishFirst! Zambia* activity trained African and youth researchers and U.S. undergraduate and graduate students/interns of both genders. The *Vaccines for Tilapia* activities to identify fish disease pathogens targeted young farmers, including women.

- **Private Sector Engagement:** The *FishFirst! Zambia* team collaborated with Sylva Food Solutions—a multi-sectoral Zambian enterprise that mass produces, brands, markets, and exports prepackaged foods for African and European markets—to produce two ComFA+Fish Instant Porridges for sensory panel evaluations.
- **Digital Engagement:** The *Zambia Crayfish* activity used a paper-based survey as the pilot to gather information about crayfish harvesting practices and basic postharvest utilization. After piloting the survey and analyzing the context, it was turned into an online survey using Qualtrics.

In-Country Partner Organizations: WorldFish, University of Zambia, Cultivating New Frontiers in Agriculture, Natural Resources Development College, Aller Aqua Zambia, Central Veterinary Research Institute, Ministry of Fisheries and Livestock, Copperbelt University, Sylva Foods.

A summary of the Phase 1 accomplishments per country and Fish Innovation Lab indicator is presented in Tables 1–4. A full list of indicator results for FY23 is shown in Appendix 2. A summary of Fish Innovation Lab success stories by activity and by year are presented in Appendix 3.

Table 1: Summary of Annual and Phase 1 Country Accomplishments, Indicator EG.3.2-1

EG.3.2-1: Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training									
	2020	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Male	0	516	1316	1144	586	82	220	198	58
Female	0	262	895	497	174	61	89	101	72
Totals	**0**	**778**	**2211**	**1641**	**760**	**143**	**309**	**299**	**130**

Table 2: Summary of Annual and Phase 1 Country Accomplishments, Indicator EG.3-2

EG.3-2: Number of individuals participating in USG food security programs (Actuals)									
	2020	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Sex									
Male	103	1172	2131	1836	397	99	689	585	66
Female	63	601	2050	889	166	65	466	192	0
Totals	**166**	**1773**	**4181**	**2725**	**563**	**164**	**1155**	**777**	**66**
Age									
15–29	33	442	1302	1028	222	85	552	169	0
30+	133	523	2584	1581	294	78	603	606	0
Disaggrega-tion not available	0	808	295	127	47	1	0	0	79
Totals	**166**	**1773**	**4181**	**2736**	**563**	**164**	**1155**	**775**	**79**

Table 3: Summary of Annual and Phase 1 Country Accomplishments, Indicator EG.3.2-7

EG.3.2-7: Number of technologies or management practices under research, under field testing, or made available for transfer as a result of USG assistance (Actuals)									
EG.3.2-7: Plant and animal improvement research	**2020**	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Status									
Phase 1: Under research	1	4	5	4	3	1	0	0	0
Phase 2: Under field testing	0	1	3	2	1	0	0	0	1
Phase 3: Made available for transfer	0	0	0	1	1	0	0	0	0
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	0	2	0	0	0	2	0
Totals	**1**	**5**	**8**	**9**	**5**	**1**	**0**	**2**	**1**
EG.3.2-7: Production systems research	**2020**	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Status									
Phase 1: Under research	1	4	5	5	2	1	0	1	1
Phase 2: Under field testing	0	10	7	6	0	2	0	4	0
Phase 3: Made available for transfer	0	0	14	17	0	2	2	13	0
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	1	5	0	1	1	3	0
Totals	**1**	**14**	**27**	**33**	**2**	**6**	**3**	**21**	**1**
EG.3.2-7: Social science research	**2020**	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Status									
Phase 1: Under research	0	1	7	8	4	0	0	2	2
Phase 2: Under field testing	1	3	3	3	0	0	0	1	2
Phase 3: Made available for transfer	0	2	3	4	2	0	1	1	0
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	1	1	0	0	0	1	0
Totals	**1**	**6**	**14**	**16**	**6**	**0**	**1**	**5**	**4**

Table 4: Summary of Annual and Phase 1 Country Accomplishments, Indicator EG.3.2-24

EG.3-2-24: Number of individuals in the agri-food system who have applied improved management practices or technologies with USG assistance									
	2020	**2021**	**2022**	**2023**	**Bangladesh**	**Cambodia**	**Kenya**	**Nigeria**	**Zambia**
Sex									
Male	0	145	1031	727	23	22	42	627	13
Female	0	11	472	257	1	10	26	182	38
Not applicable			270	2537	1216	0	1321	0	0
Totals	0	156	1773	3521	1240	32	1389	809	51
Age									
15–29	0	45	326	375	2	4	27	309	33
30+	0	104	1274	1669	1205	28	41	377	18
Not applicable	0	7	173	1477	33	0	1321	123	0
Totals	0	156	1773	3521	1240	32	1389	809	51

Fish Innovation Lab Overview and Structure

Funded by USAID, the Fish Innovation Lab aims to reduce poverty and improve nutrition, food security, and livelihoods in developing countries by supporting the sustainable development of aquaculture and fisheries. To achieve these goals, during Phase 1 the Fish Innovation Lab supported research and capacity-building activities targeting three program areas:

1. **Advancing productivity:** The Fish Innovation Lab worked to identify and develop scalable technologies and practices that enhance opportunities for prosperity, nutrition, and resilience in aquaculture and fisheries, with the overarching objective to enhance food and nutrition security. This included developing innovations to increase achieved yield of fish in aquaculture, improving availability and nutritional quality of feed (especially removal of fishmeal and fish oil), improving genetics and reliability of fish seed, and enhancing sustainable fisheries management to improve harvest yields and increase reliability.
2. **Reducing and mitigating risks:** These Fish Innovation Lab activities identified and developed scalable technologies and practices that promoted resilience and mitigated food security risks, especially through improved fish and environmental health. This included increasing the tolerance of fish to biotic and abiotic stresses (including ecological resilience), improving diagnostic capabilities, maintaining healthy and bio-secure production environments, and reducing pre- and postharvest losses (including ensuring food safety).
3. **Improving human outcomes:** This Fish Innovation Lab program area generated evidence on how to sustainably and equitably improve economic opportunity, nutrition, and resilience in aquaculture and fisheries value chains, households, and communities. This included identifying how aquaculture and fisheries can help improve nutrition and market opportunities (especially for vulnerable populations), equitable access to production assets (especially for women and youth), and establishment of an enabling environment for fish production.

Rationale for Aquaculture and Fisheries

Fish are a nutrient-rich and highly traded food commodity; as such, they are a unique global resource that offers opportunity for the Feed the Future Initiative to accomplish the goals of the Global Food Security Strategy for sustainable and equitable agriculture-led economic growth, strengthened resilience in people and systems, and improved nutrition, particularly for women and children. Globally, fish provide more than 3.3 billion people with 20% of their average per capita intake of animal proteins, reaching 50% or more in countries such as Bangladesh, Cambodia, Ghana, Sierra Leone, Indonesia, Mozambique, and small-island developing states (FAO 2022). To meet the growing demand for food and quality protein (especially animal source protein), reduce potential conflicts over natural resources, and ensure equitable access to fish, innovations are needed in both aquaculture and fisheries to foster sustainable, resilient, inclusive, and profitable production and marketing systems.

The aquaculture and fisheries sectors are important to global food security because

1. **Fish provide high-quality animal protein and micronutrients**, including vitamins A, B12, zinc, iron, and selenium. In many of the Feed the Future countries (examples listed above), fish are the primary source of animal protein; thus, increased consumption of fish and/or fish products has potential to reduce childhood stunting and improve brain development and function.

2. **Fish are one of the most widely traded agricultural commodities worldwide**; increased trade (local and regional) has potential to improve livelihoods and increase incomes.
3. **Aquaculture and fisheries provide formal and informal employment opportunities** for women and youth.
4. **Aquaculture enables diversification of farming systems** through opportunities such as integrated aquaculture, providing increased economic resilience for producers.

Fish Innovation Lab Pillars

The Fish Innovation Lab funds **research for development**, which generates knowledge, innovations, and technologies and transfers information and innovations to stakeholders for achievement of impacts. Research for development requires scientific rigor, awareness of local context, and building of relationships to enable adoption and scaling. It is not an abstract quest for fundamental knowledge or the improvement of scientific theories, nor is it the straightforward delivery of goods and services associated with development work.

During Phase 1, Fish Innovation Lab strategies were based on these pillars:

1. **Technology Innovations:** Innovative technologies to advance aquaculture and fisheries production result from productive collaborations among universities, private industry, government research agencies, and producers.
2. **Behavior Change:** Effective implementation of sustainable aquaculture and fisheries often requires voluntary behavioral changes among producers and fishers to comply with best practices. Socioeconomic research, therefore, is often required to determine the best methods to change behaviors.
3. **Value Chain Linkages:** Small-, medium-, and large-scale farms require linkages and support from private investors and industries up and down the value chain. Infrastructure development for industries to support producers (e.g., feed mills, seed stock production, harvesting and hauling equipment and services, and processing plants) is necessary for sustainable aquaculture development.
4. **Local Capacity Development:** Ensuring local institutional capacity that endures beyond Fish Innovation Lab-sponsored activities is achieved most effectively by building capacity in partner organizations. One of the Fish Innovation Lab's goals is to build cooperative learning programs that foster two-way learning and the exchange of ideas and expertise between U.S. universities and international partners.

Theory of Change and Results Framework

The Fish Innovation Lab Phase 1 theory of change posited that: ***If*** innovative technologies from universities and NGOs are more effectively developed and transferred to aquaculture producers and commercial support industries (particularly in feed and seed production), aquatic animal health and biosecurity capacity is effectively engaged to support aquaculture, behavior changes in producers and fishers are adopted to use sustainable practices, and equitable access to fish markets is enabled for fish producers and consumers, ***then*** goals of improved profitability and sustainability in fish production, increased resilience to cope with disease outbreaks and other threats, and more nutritious diets for vulnerable individuals (especially children and women) can be realized.

All Fish Innovation Lab Phase 1 activities connected to this theory of change and included three approaches, as specified in the Fish Innovation Lab Phase 1 results framework:

1. **Research for development:** Increased end-user aquaculture and fisheries research results promote sustainable, resilient intensification of production systems, enhance food safety and nutrition, increase trade and domestic market opportunities, and contribute to responsible aquatic resource management.
2. **Capacity building:** Activities result in increased capacity of local partners to independently generate and transfer fish-related knowledge, technologies, and practices to beneficiaries.
3. **Adoption of innovation and scaling:** Activities yield increased adoption of new technologies and practices as well as other innovations.

Goals and Objectives

The overarching goal of the Fish Innovation Lab is to alleviate poverty and improve nutrition through reliable provision of fish, a nutrient-rich animal source food. Like all Feed the Future Innovation Labs funded by USAID, the Fish Innovation Lab will reach its goal by supporting a research-for- development program that will be composed of competitive subawards, commissioned research, and collaborations with international partners (universities, NGOs, private sector, and governmental research agencies). Buy-Ins and associate awards will be used to extend Fish Innovation Lab activities and expand countries that are reached. In Phase 1, the Fish Innovation Lab ME implemented activities that aligned with the following three objectives:

1. Advance aquaculture and fisheries productivity
2. Reduce and mitigate risks to aquaculture and fisheries
3. Improve human outcomes from the aquaculture and fisheries sector

These three objectives aligned with the Fish Innovation Lab's three Phase 1 areas of inquiry, which were the focus of the Fish Innovation Lab research-for-development and capacity-building activities from 2018 to 2023. The activities undertaken within these objectives were implemented in four phases:

1. Quick Start activities (one-year activities awarded in FY19)
2. Competitively awarded activities (two- or three-year activities awarded in FY20)
3. Direct commissioned activities (one- or two-year activities awarded in FY21)
4. A Buy-In activity (awarded in late FY21)

Research Strategy Development

The Fish Innovation Lab Phase 1 research strategy provided a framework for the cumulative contributions of the diverse set of research activities implemented. The research strategy enabled the ME and ME Partners (cross-cutting theme specialists and regional specialists) to leverage the potential for comparative analysis between country contexts. It also helped ensure complementary research across the three areas of inquiry in support of Fish Innovation Lab intended results.

The research strategy was developed using a participatory approach in FY21. The ME and ME Partners developed an overarching research strategy for the Fish Innovation Lab based on its activities. From this, the Fish Innovation Lab research teams, ME Partners, and EAB selected

three priority questions that were relevant across multiple research activities/countries:

1. How can improved technologies and practices identified in the Fish Innovation Lab be effectively promoted for adoption by aquaculture producers and hatchery owners? *(Area of Inquiry 1)*
2. How can improved technologies and practices identified in the Fish Innovation Lab be incentivized for adoption to mitigate pre- and postharvest losses in aquaculture and fisheries? *(Area of Inquiry 2)*
3. How can increased availability through production and access to fish across the value chain address barriers to food, nutrition, and women's economic opportunity? *(Area of Inquiry 3)*

Activities that addressed the research strategy questions across teams and countries included:

- Fish Innovation Lab Nutrition Specialist Lora Iannotti and the ME communications team hosted a virtual side event at the 2021 Norman E. Borlaug International Dialogue in October. The event, entitled "Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches," aimed to inspire conversation around transforming food systems through the use of fish foods for nutrition security. The 2021 World Food Prize Laureate Shakuntala Haraksingh Thilsted gave closing remarks. The event highlighted four research activities from the Fish Innovation Lab that tested innovative, sustainable approaches to ensuring access to fish foods for vulnerable groups (Area of Inquiry 3).
- The Fish Innovation Lab presented in two panel sessions at the virtual October 2021 conference on Cultivating Equality: Advancing Gender Research in Agriculture and Food Systems. Gender and Youth Equity Specialists Kathleen Ragsdale and Mary Read-Wahidi participated in the panel on "Gender Across USAID's Feed the Future Innovation Labs: Lessons and Approaches That Cultivate Gender-Transformative Agricultural Development." Seth Adu-Afarwuah and Brietta Oaks, PIs of the activity on Micronutrient Impact of Oysters in the Diet of Women Shellfishers, participated in the panel on "Women Shellfishers and Food Security in West Africa" (Area of Inquiry 3).
- In June 2022, the Fish Innovation and Aquaculture Africa Magazine jointly hosted a series of four webinars that unpacked important lessons from the Fish Innovation Lab's activities in Nigeria (Areas of Inquiry 1, 2, and 3).
- In July 2023, the Fish Innovation Lab held a Bangladesh Aquaculture Sector meeting at BAU in Mymensingh. The meeting provided an opportunity to disseminate research findings from five Fish Innovation Lab-funded activities in Bangladesh to key aquaculture sectors stakeholders (Areas of Inquiry 1, 2, and 3).
- In collaboration with WorldFish, the Fish Innovation Lab held a workshop on "Nigerian Aquaculture: Status, Prospects, and Future Growth" at the IITA in Ibadan, Nigeria, from October 31–November 2, 2022. This in-person meeting was an important opportunity for Fish Innovation Lab teams working in Nigeria to present research findings to key stakeholders, engage in meaningful discussions about aquaculture, and raise awareness among researchers about opportunities for adoption and scaling of technologies that can support aquaculture sector growth (Areas of Inquiry 1, 2, and 3).

Research Activity Reports: Summary of Life of Activity Achievements

The following section summarizes the key achievements, lessons learned, and impacts from each research activity. A list of datasets organized by country and activity is available in Appendix 6. A list of presentations and peer-reviewed publications organized by country and activity is available in Appendix 7.

Objective 1: Advance Aquaculture and Fisheries Productivity

Quick Start Activity 1.1: From Harvest to Plate: An Analysis of the Aquaculture Postharvest Chain in Nigeria (Nigeria Cold-Chain Analysis)

Location: Nigeria

U.S. PI: Julius A. Nukpezah, PhD, Mississippi State University
U.S. Co-PI: Joe Steensma, EdD, MPH, Washington University in St. Louis
HC PI: Tran Van Nhuong, PhD, WorldFish

Objectives: The goal of the activity was to conduct a comprehensive analysis of the aquaculture postharvest chain of Nigeria to better understand the fate of harvested fish from production to consumption. The specific objectives were to

1. Identify technologies and practices that provide income growth and improve diets, including postharvest loss reduction.
2. Identify and map the aquaculture market systems that improve productivity and reduce postharvest losses of aquaculture fish.
3. Identify gaps in the aquaculture postharvest sector in Nigeria.

Executive Summary: To support Nigeria's fish-sector development, this activity aimed to improve the contribution of aquaculture fish to the diet and household incomes of the Nigerian people, including poor and vulnerable women and children. The goal of the project was to conduct a comprehensive analysis of the aquaculture postharvest chain of Nigeria to better understand the fate of harvested fish from production to consumption.

Postharvest Value-Chain Structure

Fieldwork revealed that postharvest aquaculture value chains in Nigeria were short and simple, though there were variations in value-chain configuration and coordination among studied states. Value chains in states with more aquaculture production, such as Lagos, Ogun, Delta, and Rivers, had a higher level of complexity than those with less aquaculture production. In all states, value-chain actors had limited cold-storage facilities. From farm to fork, aquaculture fish products were marketed and sold in different forms, including live fish, fresh fish, and smoked fish. Given the poor infrastructure for transportation and limited electricity supply, value-chain actors kept products for a short duration then sold to next actors.

Postharvest Loss Along Aquaculture Value Chains

In Nigeria, where access to electricity and a cold chain can be an issue, fish losses can be significant. Postharvest losses can be due to mishandling and contamination during transporting, storing, processing, and waiting at markets to be sold. This study showed that total fish losses in Nigeria overall were surprisingly low (less than 2%). Fish losses from small-scale aquaculture were slightly higher than losses from large-scale aquaculture for both catfish and tilapia. For small-scale aquaculture, catfish losses were lower than for tilapia mainly because catfish has a higher tolerance to space and water-quality constraints during transportation and can be sold live in the market.

Characteristics of Aquaculture Production Systems in Nigeria

The most common aquaculture systems used by smallholder aquaculture farmers were earthen ponds (58%), concrete tanks (38%), fiber-plastic tanks (12%), and tarpaulin tanks (15%). Collapsible ponds, cage aquaculture, flow-through raceways, recirculating aquaculture systems, and burrow pits were other production facilities in use. Analysis showed that aquaculture production systems operated by smallholders were characterized by small production facilities.

To assess economic performance, the team conducted a benefit-cost analysis of catfish aquaculture practiced by small farmers in Nigeria in major production systems. The results of this analysis suggested earthen ponds had higher profitability (1.75) followed by concrete tanks (1.62) and other production systems (1.56). On average, for each dollar of investment, farmers got back 0.64 dollars ($0.64) gross margin. Due to low operation costs, earthen ponds had the highest benefit-cost ratio compared to concrete tanks and other production facilities.

In terms of benefit-cost analysis of tilapia aquaculture performance was poor, with an average of 1.17 for the whole sample and 1.09 for earthen ponds. Other production facilities experienced a negative net return and resulted in a benefit-cost ratio of 0.55. There are several important implications for tilapia aquaculture assessment. First, it is not a popular aquaculture species in Nigeria. Only 19 of 648 surveyed farmers reported farming tilapia in 2018. Second, tilapia was included as a species in polyculture with catfish, and the production objective likely was to provide feed to catfish. In other words, aquaculture farmers in the surveyed sample may not pay equal attention to tilapia as to catfish.

Aquaculture Contributions to Rural Livelihoods and Household Incomes

High demand for fish was one of the important motivations for farmers to engage in aquaculture production. This study showed that aquaculture is a profitable activity that can contribute to household income. For more than 75% of survey respondents, aquaculture contributed more than half of their household's income. However, there were only 25% of respondents who focused on aquaculture as the only livelihood/income-generating activity. In addition to aquaculture, farmers also engaged in other businesses, agriculture production (mainly crop farming), and trading.

Women and Youth Engagement in Aquaculture

Results indicated gendered roles in aquaculture value chains in Nigeria. For example, men were more likely to participate in aquaculture production and processing activities, while women were more active in trading, wholesaling, and retailing activities. The top challenges faced by women included cultural barriers, lack of capital and difficulty accessing financial resources, low risk-taking attitudes of women, and poor infrastructure. Lack of technical knowledge was also commonly found to constrain women's engagement in aquaculture-related livelihood activities.

Summary: The Aquaculture Postharvest Sector in Nigeria

Through this investigation, gaps in understanding of the aquaculture postharvest value chain have been filled. Postharvest losses are not as pronounced as what might otherwise have been presumed, and the overall efficiency of the aquaculture sector is not as profoundly impacted by postharvest losses as was originally hypothesized. This study demonstrates potential opportunities for greater investment in training and technical-skill development among women and youth to improve postharvest value. Further, it demonstrates that catfish—due to its hardiness and variety of preparations—has less postharvest loss than tilapia (though both species have low postharvest loss). Overall, growth in demand and increasing competition should continue to drive efficiency within the value chain, including postharvest activities.

Lessons Learned

The study found that there is limited access to cold chain facilities in Nigeria. To cope with this, value-chain actors keep transportation time short to maintain freshness and avoid spoilage. The average fish transport times for fresh tilapia and catfish were low (1.38 hours and 1.89 hours, respectively). A lesson learned was that postharvest losses are not pronounced and do not have a profound impact on the sector. Although both have low postharvest loss, catfish (due to its hardiness and variety of preparations) has less postharvest loss than tilapia.

Quick Start Activity 1.2: Replacing Fishmeal with Single-Cell Proteins in Tilapia (*Oreochromis niloticus*) Diets in Zambia (Zambia Feeds)

Location: Zambia

U.S. PI: Delbert Gatlin, PhD, Texas A & M University
U.S. Co-PI: Don Corace, Meridian Biotech
U.S. Co-PI: Wes Baumgartner, DVM, PhD, Mississippi State University
HC PI: Rodrigue Yossa, PhD, WorldFish
HC Co-PI: Rose Komugisha Basiita, PhD, WorldFish
HC Co-PI: Alexander M. Greiling, Aller Aqua Zambia
HC Co-PI: Masautso Sakala, Natural Resources Development College

Objectives: The purpose of this study was to investigate the effect of partially or totally replacing fishmeal by single-cell protein ingredients in a tilapia (*Oreochromis niloticus*) commercial feed. The specific objectives were to

1. Study the effect of partial or total replacement of fishmeal by SCP on the growth, survival, nutrient utilization, condition factor, and gut health in tilapia.
2. Estimate the optimum level of substituting fishmeal with SCP in tilapia diets.
3. Determine whether the SCP product is appropriate for tilapia nutrition.

Executive Summary: This activity investigated whether the DY-Pro, a single-cell protein produced by Meridian Biotech in the United States, could be used as an alternative protein ingredient to substitute fishmeal, thus supporting the sustainable growth of tilapia farming globally. In this partnership between public and private entities in the U.S. and Zambia, the research team conducted a feed trial to study the effects of graduated amounts of DY-Pro ingredient in feeds used for tilapia aquaculture in Zambia.

Feed Processing, Animal Sourcing, Acclimating the Fish

Aller Aqua Zambia supplied the feed ingredients, and Texas A&M University produced seven experimental feeds, in which graded levels of DY-Pro were substituted for fishmeal. The diets were based on practical ingredients, and the control diet contained 14.85% fishmeal. Once made, the diets were shipped to Zambia where WorldFish Zambia received them and kept them frozen at the Natural Resource Development College (NRDC) (in the freezer purchased by the project) until the start of the experiment. Yalelo Zambia supplied the experimental tilapia, which were then acclimated at the newly constructed facility at NRDC. This acclimation period also served the purpose of testing the functioning of the new facility.

Upgrade of the Fish Facility

The fish facility at NRDC in Lusaka, Zambia, was upgraded through the design and building of a flow-through aquaculture system composed of 30 aquaria, a steel structure with three layers (levels), one 2000-L tank, one 1000-L tank, one air blower, one water pump, piping, and other materials.

Completion of the Experiment

The experiment effectively started in the newly constructed fish facility at NRDC. Eleven fish were stocked in each aquarium, with an average body weight of 11 g per fish, for a total of 330 fish stocked in the 30 aquaria. When the experiment was completed, data on fish growth, feed intake, and water quality were collected. The proximate composition of the fish and feed samples was analyzed in a local lab in Zambia, and gut samples were shipped to MSU for gut immunohistochemistry analysis.

Results of the research activities associated with this project demonstrated that the use of DY-Pro in the diet of tilapia could replace all of the fishmeal provided in the control diet (14.85%) without any significant negative effects on fish growth or body condition factor. It is worth noting that there was a significant ($P<0.05$) negative linear regression between the replacement level of fishmeal by DY-Pro and feed intake and FCR (amount of feed required per unit body weight gain). The increase in the replacement level of the fishmeal by the DY-Pro led to a decrease in the feed intake and FCR but showed similar growth performance as fish fed the control diet. As such, DY-Pro could effectively help reduce pressure on the fisheries stocks by replacing all of the fishmeal provided in the control diet without negatively impacting fish weight gain, feed conversion, or health of the fish.

These feed-trial results show that tilapia given DY-Pro consumed less feed to achieve the same growth than tilapia given fishmeal feed, indicating that DY-Pro is a more efficient feed ingredient, which can save producers on costs. These potential cost savings, as well as potential environmental benefits of a more sustainable feed ingredient, indicate that single-cell-protein technology provides a promising alternative feed ingredient for tilapia aquaculture in Zambia and other locations.

All research partners worked actively to achieve the project milestones, and the experiment was effectively completed with the active participation of all project partners and two young NRDC interns, one woman and one man, hired to support the project while developing their aquaculture and research capacities. These interns gained extensive technical and scientific aquaculture and research experiences throughout the project.

Lessons Learned

The activity demonstrated that the use of DY-Pro tilapia diet can effectively help reduce the pressure on fisheries stocks by replacing 100% fishmeal in the tilapia diet without any significant effects on fish growth and condition factor. The research found a significant ($P<0.05$) linear regression between the replacement level of the fishmeal by the DY-Pro and the feed intake and FCR. The increase in the replacement level of the fishmeal by the DY-Pro leads to a decrease in the feed intake and FCR.

Quick Start Activity 1.3: Genome Sequencing and Development of Single Nucleotide Polymorphism Markers from Rohu in Bangladesh (Rohu Sequencing)

Location: Bangladesh

U.S. PI: Attila Karsi, PhD, Mississippi State University
U.S. Co-PI: Dan Peterson, PhD, Mississippi State University
HC PI: Md. Samsul Alam, PhD, Bangladesh Agricultural University
HC Co-PI: Md. Akhtaruzzaman Khan, PhD, Bangladesh Agricultural University
HC Co-PI: John Benzie, PhD, WorldFish
HC Co-PI: Matthew Hamilton, PhD, WorldFish

Objectives: The research goal was to improve aquaculture production and the livelihoods of farming communities in Bangladesh and surrounding regions by implementing sustainable genetic approaches. The objectives of the Quick Start activity were to

1. Establish collaborations and conduct stakeholder surveys.
2. Conduct sequencing of the rohu (*Labeo rohita*) genome.
3. Identify genome-wide single nucleotide polymorphisms (SNPs).

Executive Summary: Aquaculture and capture fisheries are vital to food security and human nutrition. Aquaculture is expected to play a key role in meeting increasing human food and nutritional demands. Rohu (*Labeo rohita*) is primarily cultured in polyculture systems (those that cultivate more than one species) by small- and medium-scale farmers in Bangladesh. It is a highly preferred fish that is consumed by all income groups. This activity addressed knowledge gaps in technology adoption by rohu carp producers, causes of yield losses, and profitability of rohu carp production in Bangladesh. Furthermore, this activity addressed lack of a high-quality rohu carp genome and SNPs for marker development, which limit progress of breeding programs to improve rohu carp genetics.

Stakeholder Surveys

The stakeholder survey results revealed that rohu-based carp polyculture was profitable where gross margin, net margin, and benefit-cost ratio were found to be positive. Results related to technical efficiency indicated that the farmers were efficient; nevertheless, the sample farmers operated well below the production frontier and, therefore, still had opportunities to achieve improved yields. The yield gap existed due to inefficient farming practices and technical biotic (e.g., diseases) and abiotic (e.g., flooding or drought) constraints.

However, the results indicated that abiotic factors were more responsible than biotic factors for yield losses in the study areas. Productivity and efficiency were positively related, where small farms were more productive and efficient than large farms. The results also revealed that a considerable portion of farmers was young (18–35 years old) in the study areas, and young farmers were more productive and efficient than older farmers (51 years or older). Most of the farmers preferred rohu as the main species in carp polyculture because of its higher production, high market demand, better feed conversion, and better taste and flavor. In terms of daily fish consumption, rohu alone contributed to more than half of total fish consumption among respondents and significantly contributed to their daily protein requirements. Since feed is the most costly aquaculture input, greater attention should be paid to feed price to promote carp polyculture. Farmers should be encouraged to apply the correct dose of inputs in their ponds to enhance productivity and ultimately reduce the yield gap.

Sequencing the Rohu Genome

After sequencing, the assembled rohu genome size was about 939.5 million base pairs (Mb) in length, a value less than half the previously reported size of the rohu genome as determined by Feulgen densitometry (1950 Mb), which is a common method used to determine deoxyribonucleic acid (DNA) content. To explore this discrepancy, the project team used flow cytometry to determine the rohu genome size and found it was close to the assembled genome size (968 Mb on average for five male rohu with two determinations per fish). This suggests that the earlier Feulgen densitometry determination of rohu genome size was likely flawed. The team's assembly of the rohu genome is the most contiguous rohu genome available, composed of 6,175 scaffolded fragments, with more than half of the total genome in 26 fragments (L50), each of which is longer than 1.29 Mb (N50). Computational predictions indicated the rohu genome has 29,494 genes with 30,480 mRNAs.

Identifying SNPs

To identify SNPs, the project team compared the genome sequences of rohu carp collected from three different river systems (Padma, Jamuna, and Halda) to the genome assembly. About

99% of the carp sequences matched the genome assembly, and 1,033,085 SNPs were predicted. The SNP differences between fish correlated with the geographical distances between their rivers of origin. The predicted SNPs can be correlated with measured physical traits of rohu carp (such as growth rate) to enable the development of markers for beneficial or detrimental gene variants, accelerating and improving the effectiveness of breeding programs.

Conclusions and Recommendations

This study revealed that rohu-based carp polyculture in Bangladesh was profitable. The yield could be increased through maximizing efficiency, curtailing the yield gap, and increasing participation of young farmers. Fish farmers and their households consumed more fish than the national average, and rohu was preferred due to its better taste and flavor.

Availability of rohu genome and SNP markers provided much-needed genetic tools to initiate broodstock improvement programs for rohu. Linking SNP markers with better performing rohu would accelerate rohu genetic selection. Improved rohu broodstock would increase rohu aquaculture, profitability, and food security.

Based on the results of this study, the following recommendations are suggested:

1. The price of feed should be reduced while feed quality should be improved.
2. Cultural practices should be improved to reduce yield gaps.
3. Young entrepreneurs should be encouraged to participate in the aquaculture business.
4. Government and NGOs should assist farmers in their economic decisions on aquaculture practices.
5. Research linking SNP markers with measurable physical traits should be supported.
6. Research developing superior broodstock through marker-assisted selection should be supported.
7. Once developed, superior broodstock should be provided to farmers.

Lessons Learned

The study found that rohu-based carp polyculture is profitable. The gross margin, net margin, and benefit-cost ratio were all found to be positive. A technical efficiency analysis showed that the farmers were efficient, but the sample farmers nevertheless operated well below the production frontier. The yield gap was due to inefficiency of farmers and technical constraints (biotic and abiotic). The results indicate that abiotic factors were more responsible for yield loss than biotic factors. Productivity and efficiency were positively related where small farms were more productive and efficient than large farms. The results also revealed that a considerable portion of farmers were young, and that young farmers were more productive and efficient than older farmers. Most of the farmers preferred rohu as the main species in carp polyculture practice because of higher production, higher market demand, better feed conversion, and better taste and flavor. In terms of daily fish consumption by producer families, rohu alone contributed more than half to the total fish consumption and had significant contribution on daily protein requirements. Because feed cost is the highest aquaculture input, greater attention should be placed on feed price to promote carp polyculture practice. Furthermore, farmers should be encouraged to apply the right amount of inputs to their ponds, which would enhance productivity and reduce the yield gap.

Identification of SNPs in the rohu carp genome demonstrated that genetic analysis to support selection and improvement of rohu production traits is feasible.

Activity 1.1: Aquaculture and Rural Communities: Integrated Agriculture-Aquaculture as Farm Diversification Strategy (Aquaculture Diversification in Rural Communities)

Location: Nigeria

Lead PI: Matthias Halwart, PhD, Food and Agricultural Organization of the United Nations
Lead Co-PI: Yuan Xinhua, PhD, Food and Agricultural Organization of the United Nations
U.S. PI: Amrit Bart, PhD, University of Georgia
U.S. Co-PI: Esendugue G. Fonsah, PhD, University of Georgia
U.S. Co-PI: Gary J. Burtle, PhD, University of Georgia
HC PI: E. K. Ajani, PhD, University of Ibadan
HC Co-PI: B. O. Omitoyin, PhD, University of Ibadan

Objectives: The activity goal was to secure supply and access to rice and fish, improve nutrition-sensitive diets, promote resource use efficiency, and generate employment and better livelihood options in the selected communities. Present challenges relevant to the future needs of vulnerable populations were to be addressed through appropriate research and targeted interventions. The activity aimed to demonstrate the importance of technology innovations for enhancing and sustaining aquaculture production, economic opportunities for youth and women, and resilience of rural communities to food and nutrition security challenges. The objectives were to

1. Consider the technologies that are accessible to local farmers and analyze how integrated agriculture-aquaculture systems influence the resilience, dietary diversity, livelihood options, rural employment (especially for youth and women), use of resources, and the role of institutional and policy innovations.
2. Study how diversification of farming systems through integrated agriculture-aquaculture systems can contribute to producing more diversified and nutritious food for the local market and rural communities with consideration for all demographic strata (women, men, and youth).
3. Study value-chain enhancement through market access facilitation and marketing management.
4. Study sustainability and long-term support of capacity development of farmers, extension workers, university students, and value-chain actors for activity goals within and beyond activity locations.

Executive Summary: The Aquaculture Diversification in Rural Communities team implemented a research-for-development activity with small-scale rice farmers and extension workers in two states of Nigeria, Kebbi and Ebonyi. Integrating agriculture and aquaculture by introducing fish into rice farming aims to transform existing rice farming to become more productive, climate-friendly, and resilient. The team prioritized culturally acceptable and easy-to-implement practices to ensure sustained adoption with long-term benefits for the farming communities. The activity, jointly implemented by the FAO, UI in Nigeria, and the University of Georgia in the U.S., worked closely with rural smallholder rice farmers and extension staff to implement on-farm demonstration trials. The team also undertook a series of analyses and participatory community appraisals to assess current farming systems and identify entry points for the farm diversification strategy.

The team documented key features of agricultural production and mapped wetland areas in Kebbi and Ebonyi States, identifying suitable areas for rice and fish farming. The seasonal calendar of farming activities is conducive to rice cultivation two times a year—depending on annual rainfall patterns—thus presenting the opportunity for fish farming twice a year.

The team conducted a baseline analysis of food security and nutrition, which indicated severe food insecurity in the communities. Integrated rice-fish farming could increase farm yields while enhancing food and nutrition security and increasing incomes.

The activity created an innovation platform on integrating agriculture and aquaculture, which served as a forum for farmers, extension workers, researchers, and other stakeholders to jointly discuss progress and co-develop solutions to issues encountered during the farm diversification process.

Working With Farmers to Diversify Production

The team used the experimental outcomes and lessons learned from the rice-fish trials to develop a technology guide enabling more than 100 rice farmers with little or no knowledge of aquaculture to successfully introduce fish into their rice fields, and as a result, rice-fish farming clusters are now emerging in rice-growing communities of Kebbi and Ebonyi States. To facilitate the adoption process, the team trained over 700 farmers and prepared technology guides with practical advice on management of rice fields and fish crops in integrated systems, water use and management, and business plan models, which can then be locally adapted. Opportunities for improvement include locally available feeds and postharvest processing as a good strategy to increase the value of fish.

Identifying Locally Available Feed Ingredients

Feed costs typically are the major expense in aquaculture operations. The farming of fish in rice fields offers the advantage of “free food,” but farmers can obtain higher fish yields with supplementary feeding. Therefore, the team identified and tested locally available feed ingredients for application in the rice-fish system: rice bran and fish offal meal as energy and protein in fish feed. The experimental study on nutrient digestibility of these feed ingredients revealed that both rice bran and fish offal meal were suitable for African catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*). The results also showed that catfish fed with the locally available feed formulations reached similar optimum growth performance compared to those fed with conventional feeds, and in particular, the fish grew faster when fish offal meal was provided.

Main Conclusions and Recommendations

The farm diversification trials demonstrated how including fish in rice farming can boost more efficient use of resources and higher production, supply locally produced, nutritious food for home consumption, and generate income through selling fish. More rice and fish are available to the communities, decreasing hunger. These results were well received by hundreds of rice farmers in Kebbi and Ebonyi States, demonstrating a prime opportunity to consolidate successes and lessons learned to replicate, expand, and scale the farm diversification (rice-fish) activities in these states and beyond using participatory approaches. The main conclusions and recommendations of the activity include the following:

- Diversification of rice-based systems with fish is a viable strategy providing higher returns than rice monocropping and should be promoted through participatory approaches such as Innovation Platforms or Farmer Field Schools together with local extension systems and agents.
- Fish becoming available locally from integrated rice-fish systems increases household dietary diversity and/or generates income used for the food budget, thus addressing the high prevalence of food insecurity. These results should be documented in local languages and disseminated widely for upscaling in Ebonyi, Kebbi, and other states of Nigeria.

- Postharvest processing using smoking kilns increases the value of smaller fish available at rice harvest. This can compensate for the market preference for larger fresh fish, and this and other options for value addition should be further tried and promoted as part of the participatory field schools.
- The reduced use of chemicals in integrated rice-fish systems leads to better ecosystem health and increased biodiversity utilized by households. Further studies are recommended to quantify these effects in terms of cost savings and health of the farming environment and communities.
- The use of locally available feed ingredients reduces feed costs for the farmer, is more efficient and climate-friendly, and enhances resilience. Other feed ingredients, including novel alternatives such as insect larvae, may also be tested for inclusion in locally produced feeds that reduce dependency on costly imported feeds and increase the resilience of the farms and farmers.

Lessons Learned

1. Water retention in rice field trenches: Leaching of water and rapid evaporation were observed during the dry season. In the absence of a working irrigation structure, the additional cost of pumping water for replenishment may not be sustainable for farmers with limited financial resources. The initial adaptation measure employed was to lay plastic bags inside the trenches to hold water for a longer period. However, in terms of environmental sustainability, the use of plastic lining was discouraged, and thus rice-fish farming is encouraged during the wet/rainy season.
2. Fish seed availability: Limited access to fish seed was reported by the farmers. The solution was to train farmers on low-cost fish breeding techniques to improve availability within their locality.
3. Predation from birds: Loss of fish due to predation from birds was recorded. The use of net covering and stocking of larger fish were recommended as a preventative measure.
4. Fish size at harvest: The fish were harvested at 250–350 g after 3 months of co-culture with rice. Although the size was not competitive for the desired size in Nigerian fresh fish markets, value-addition through smoking was introduced to boost the economic value of the fish, noting that smoked fish commands high market value irrespective of size.
5. Expensive commercial feed: The cost of commercial fish feed was challenging to the farmers. The activity therefore introduced alternative feeds, using locally sourced feed ingredients (rice bran, fish offal) for feed formulation. Also, there is an ongoing process to develop a training protocol for farmers on using BSFL as an alternative fish feed.
6. Knowledge sharing among activity participants: Farm diversification processes slightly differ from plot to plot. Therefore, farmer-farmer knowledge exchange and experience sharing are considered an important aspect of knowledge transfer and information dissemination among practitioners.
7. Use of manure: Farmers have started to report positive changes in aquatic biodiversity of rice fields. In other words, they can collect other aquatic foods in addition to rice from their farm. The regeneration of aquatic biodiversity is due to reduced use of chemicals and the promotion of manure use.

Useable Outcomes

1. Wetland maps of areas suitable for rice-fish farming in Kebbi and Ebonyi States

3. Technological package on water management for rice-fish farming
4. Technological package on instructional care for rice-fish farming
5. Six manuscripts on integrated rice-fish farming developed for publication in reputable outlets
6. Integrated rice-fish farming business manual developed for Kebbi and Ebonyi States
7. A case study on rice-fish farming in Kimba, Kebbi State
8. Four policy briefs to share farm diversification technologies

Tangible Impacts

1. The knowledge for adapting rice fields to include aquaculture has impacted over 700 farmers.
2. The modified rice fields have a lifespan of 10–15 years; therefore, the farmers do not have a recurrent cost for field modification.
3. Farmers have started to report positive changes in aquatic biodiversity of rice fields. In other words, they can collect other aquatic foods in addition to rice from their farms. The regeneration of aquatic biodiversity is due to reduced use of chemicals, and the promotion of organic manure use.
4. The knowledge on fish seed production has impacted over 20 individuals.
5. The knowledge on fish smoking has been impacted on over 20 individuals.
6. Eight graduate students were trained.
7. Local institutional capacity at higher education institutions will continue to be used for teaching future students.

Activity 1.2: No Longer Bugged by Feed Costs: Farming Insects as Sustainable and Scalable Aquaculture Feedstock to Improve Catfish (*Clariidae*) Producers' and Consumers' Livelihoods Towards Food Security in Nigeria (Farming Insects in Nigeria)

Location: Nigeria

Lead and U.S. PI: Jennifer Pechal, PhD, Michigan State University
U.S. Co-PI: Simone Valle de Souza, PhD, Michigan State University
HC PI: Bolarin T. Omonona, PhD, University of Ibadan

Objectives: This activity aimed to evaluate integrated ITF farming systems: 1) costs and conversion ratios of propagating BSF and processing into aquaculture feed; 2) feasibility and cost-effectiveness of organic waste streams (e.g., market waste) for BSF farming; 3) changes in pond yield and productivity resulting from BSFL meal replacement in fish feed; 4) changes in nutrient profiles of farmed fish resulting from partial BSFL meal substitution in fish feed; 5) economic viability and impacts of women-led small-scale BSF production enterprises; and 6) effects of BSFL meal production and processing on labor, time allocation, and household income for the BSF farmers and fish farmers. The team expected fish farmers to willingly learn about and adopt BSFL meal because it is a low-cost, local-input, non-mechanized technology that can produce a substantial part of the animal protein needs of fish.

Executive Summary: Small-scale farmers make up 94% of the Nigerian fish farming sector, for whom the main hindrance in fish production is the scarcity of fish feed and high-production cost associated with fish feed. Additionally, a staggering 90% of fish catch used for fishmeal is considered food grade and could be an important source of nutrition to Nigerian communities.

There is a critical need for alternatives to fishmeal in aquaculture production since the environmental and economic issues surrounding current global protein production are growing. The potential to develop a high financially valued industry via insects is a viable option for fish farmers. This activity established insect farms for an ITF farming system to work in synchrony with local fish farmers to mass rear insects, specifically BSF, as an alternative fish feed component.

Stakeholder Surveys

The study relied on primary data collected from farmers in Cross River, Ebonyi, and Oyo States, Nigeria. The team used a structured questionnaire to gather information about the farmers and their production practices, analyze costs of production including feed costs, and estimate the profitability of catfish farming. The majority of the catfish farmers were male (86.6%), married (90.9%), and had tertiary education such as college or trade school (67%). They had engaged in farming as their primary occupation (76.8%) and had been catfish farming for 1–10 years (73.8%). Approximately 60% of the farmers had two production cycles in a year. Over half (59.2%) of the farmers used both imported and locally made feeds in rearing catfish, while 37.2% and 3.7% used exclusively imported and local feed, respectively. These survey results helped inform the team's assessment of whether and how insect farming could be integrated into the value chain.

Catfish Farming Enterprise

Results from this study indicated that catfish farming is a lucrative livestock enterprise. Approximately one-third of farmers incurred total costs less than ₦3 million in Nigerian currency ($3,900 USD), while another third of farmers had costs above ₦9 million ($11,600 USD) in a year. Over half of the catfish farmers generated less than ₦4 million ($5,200 USD), and one-quarter of the farmers had more than ₦9 million ($11,600 USD) in a year. Cost of feed was the most significant total cost for the farmers at over 80%, while labor, fingerlings, lime, medications, transportation, and fertilizer jointly contributed to the remainder of the production costs. Currently, about 10% of the farmers have adopted the ITF farming system to assist in lowering aquaculture production costs.

Farmers' main challenge was the inability to continue fish farming due to high costs. The Fish Innovation Lab recommended BSF propagation for the aquaculture industry and developed training for farmers. The team collaborated with local Agricultural Development Project members to disseminate the training across states. There is still great potential for local livelihood sustainability to improve as the propagation of BSF will generate income for individuals involved across the fish value chain.

Safety of Black Soldier Fly Larvae Meal

To address potential concerns about the safety of BSFL meal, the team evaluated samples to assess microbial communities for potential pathogens. Farmers can directly benefit by selling BSF-derived value-added products such as nutrient-rich compost that is naturally produced during the BSF rearing process. Using whole genome sequencing to identify potential microbial pathogens, the team found low levels of opportunistic pathogens for humans (less than 10% of the DNA fragments analyzed), but major foodborne pathogens were not identified, and a high proportion of the DNA was unknown. This indicates that fish feed made from BSFL—which is rich in protein, fats, and oil—is safe for fish to eat and will not transmit diseases because the BSF is not a vector of disease. This makes BSFL a safe fish feed alternative for fish and humans alike. Additional analysis may yield important discoveries about the microbial community structure of BSF-derived products, which will benefit producers using the ITF farming system as well as consumers.

Solutions Through Insect-to-Fish Farming for Nigeria

This study focused on building Nigerians' knowledge, skills, and resilience to food insecurity while promoting responsible aquaculture practices. The outputs have demonstrated a capability to support locally produced, nutritious food by developing more self-reliant, resilient ITF farming systems. Local BSFL production acts as a local waste management tool while reducing the cost of fish feed for fish production. As adoption of BSF for feed expands, these activities will continue to increase food and job security for growing populations and serve as a non-competitive resource with human food production to improve sustainability of the aquaculture industry. Investing in economic opportunities and sustainable food systems, such as ITF farming systems, will empower more Nigerian families, especially women and youth, to increase future income and nutritional needs.

Recommendations

Fish farmers, including youth and women, interested in rearing BSFL should be assisted in the acquisition of the basic BSFL production knowledge and kits, especially the mating nets/cages and the larvae growth crates. These materials will incentivize farmers to produce the BSFL for fish feeding. The team found that BSFL can be successfully fed directly to the fish without compounding it into a feed. So, the lack of feed mills in Ebonyi and Cross River States will not hinder the use of BSFL in feeding of catfish across Nigeria.

Lessons Learned

1. Due to the lack of feed mills in Ebonyi and Cross River States, the team had to restructure the activity's design, changing the feed production site from the originally selected states to Ibadan, Oyo State. This delayed the distribution of materials due to logistical challenges related to transporting BSF-rearing cage materials from one region to another, ultimately affecting timelines and budgets.
2. The team experienced delays due to fuel and currency scarcity in Nigeria in late 2022 to early 2023. This situation raised awareness among the activity team about the importance of planning using principles of adaptive management.
3. The onset of the COVID-19 pandemic coincided with the inception of the activity, limiting the ability of the team to travel to implementation sites and hampering the team's capacity to better engage with participants early in implementation.
4. Due to the challenges experienced by farmers in the context of COVID-19, the global increase of input prices, and local situations such as fuel and currency scarcity, many aquaculture producers reduced or stopped fish production. However, as the activity raised awareness about the prospect that BSFL meal could reduce feed costs, some expressed interest in returning to the business of fish production.

Useable Outcomes

1. Research findings showed that BSF-supplemented feed can reduce feed costs for farmers compared to conventional feed.
2. The activity demonstrated to farmers how the BSFL can be reared safely and how to process the BSFL to feed fish.
3. Farmers learned that catfish fed with BSF feed have an appealing aroma when smoked and eaten.
4. The activity gathered data that outlines the challenges confronted by these farmers in their efforts to produce nutritious food for their local communities.

5. The team successfully identified the prevailing fish culture systems employed within the region. Through this investigation, the activity conducted a comprehensive cost comparison analysis. This analysis holds the potential to offer valuable insights and recommendations to both the local community and prospective entrants interested in embracing fish farming endeavors, particularly within the context of an integrated ITF production system.
6. The activity assessed labor composition in fish farming activities, paying particular attention to the participation of women. Additionally, the team gathered pertinent data concerning the wages remunerated for these tasks.
7. The team identified a subset of farmers who are producing their own in-house fish feed, and they documented the specific ingredients utilized in this feed production process.
8. The activity concluded that there were potential opportunistic pathogens found in BSF derived organic material, but none of these are common sources for foodborne illness.

Tangible Impacts

The capacity building for farmers to rear BSFL is a game changer for farmers to mass produce catfish at relatively low prices. This ITF production system holds the potential to contribute to enhanced nutrition among vulnerable populations and the community at large. The ability to produce fish for household consumption or local sale will foster improved access to nourishing food options. Moreover, the in-house production of fish feed is anticipated to alleviate existing challenges faced by farmers concerning high costs of imported feed as well as the availability and consistency of fish feed within the region.

Activity 1.3: Improving Efficiency in the Nigerian Aquaculture Sector by Employing Lean Production Systems (Lean Production Systems)

Location: Nigeria

Lead and HC PI: Rohana Subasinghe, PhD, WorldFish
HC Co-PI: Sunil Siriwardena, PhD, WorldFish
U.S. PI: Julius Nukpezah, PhD, Mississippi State University
U.S. Co-PI: Joe Steensma, EdD, Washington University in St. Louis

Objectives: The research objective was to improve operational efficiency, reduce postharvest losses, improve waste management, and decrease the cost of production of catfish and tilapia in Nigerian aquaculture through application of Lean production systems. The goal was to explore how Lean technology—an approach aimed to reduce waste starting from the aquaculture pond all the way to the marketplace—can be used in a low- to middle-income country context, specifically in Nigeria, to identify benefits that are conferred to small-scale fish farmers as well as larger corporate aquaculture operations and processors.

Executive Summary: The aquaculture sector has been growing at a rate faster than any other food production sector in the world. Aquaculture now contributes nearly 50% of total fish consumption worldwide. Although aquaculture is growing and is poised to contribute more to global food demand, the sector faces significant challenges and bottlenecks. Many critical issues continue to stifle aquaculture growth in Africa. Nigeria is Africa's second-largest aquaculture producer and continues to struggle to bridge the gap between production output and domestic fish consumption demand. To address bottlenecks in the aquaculture sector, this activity used the principles established by the Toyota Production System, also called Lean management, to minimize costs or maximize efficiency by eliminating waste and converting waste into value. Waste reduction and process optimization are key components to improve

quality and delivery while conserving resources like time and money. Despite the overwhelming evidence that several agricultural businesses are adopting Lean practices and benefiting from them, others in the sector are less prepared to implement the tools used in Lean management. Further, the integration and application of Lean principles to aquaculture is largely still in its infancy, yet the sector represents a huge opportunity for efficiency gains.

The activity examined the suitability and practicality of using the Lean management concept and training fish farmers on effective practices. The specific objectives were to use Lean management to improve operational efficiency, reduce postharvest losses, improve waste management, and decrease the cost of production.

Activity results showed significant improvements in aquaculture value chain efficiency in Nigeria after the intervention, which suggests that the Lean approach successfully minimized inefficiencies in fish farms in Ogun and Delta States. With rare exceptions, farmers reaped benefits from Lean training, regardless of age, gender, geographical location, company status, farm type, farm size, and annual income. Findings demonstrated the ability of Lean management practices to continue helping the Nigerian aquaculture sector and individual farmers to drastically reduce waste and become more profitable. Building a more resilient aquaculture industry in Nigeria requires equipping farmers with the tools to address different types of on-farm waste, and this study demonstrated that Lean management tools are simple to incorporate and effective.

Key Findings and Impacts

The application of Lean management principles addressed 14 domains of waste, including reduction in time, fish mortality, and labor cost. Lean management tools also contributed to efficiency in energy use, inventory space, labor, feed cost, and feed quantity. The other domains that improved were reduction in medication cost, water treatment cost, transportation cost, maintenance cost, and fish losses.

The activity trained 40 Nigerian aquaculture value-chain actors and certified them as LSMEs in aquaculture. These trainees have been equipped with the necessary tools to train others to adopt and disseminate the Lean management tools. In all, more than 340 aquaculture value-chain actors benefited directly from Lean management training, including about 20% women. Analyses demonstrate that women were good adopters of Lean innovation, as were their male counterparts, and they could help scale up the technology.

Although aquaculture in Nigeria is considered a pastime of retirees and is dominated by older people, the research team made efforts to include youth. Ten percent of participants were under 31 years old. Only 10% of participants were older than 57 years.

The activity included actors with small, medium, and large-scale aquaculture activities. Although most farmers identified as smallholders, the activity targeted participants with corporate recognition and demonstrated that Lean tools can benefit all groups.

Although pond aquaculture is the popular system of choice in Nigeria and accounted for 75% of the systems used by the participants, users of tank systems (18.5%) and other systems (6%) benefited from how Lean approaches contributed to improving the efficiency of their aquaculture production businesses.

Although the participants came from two states, outreach webinars suggest that the innovation could benefit many groups beyond the borders of these states.

Recommendations

Given the reported benefits of Lean tools in the two Nigerian states, the scope of Lean management should be expanded to other states, the West African subregion, and elsewhere in

the world by extensively disseminating the study findings through publications, conferences, webinars, etc.

Since community based LSMEs can be effective resources for disseminating Lean tools, they should be certified as trainers and paid for their services to ensure the continuity of the activity beyond its end date.

Lessons Learned

Activity findings demonstrate that Lean management principles can be applied in the aquaculture sector in Nigeria; community-based LSMEs can be effective resources for disseminating the tools; Lean training serves as an eye-opener to identify waste in the production system and the source of low profit in aquaculture businesses; Lean tools are self-applicable tools that depend little on others and are affordable, quickly learned, and easily applied; Lean tools should be replicated and disseminated among aquaculture sector operatives for improved efficiency.

Useable Outcomes

Reducing losses across the value chain by using Lean tools increased revenue for value-chain actors. This can translate into lower costs of fish production, lower cost of fish in the market, and higher fish consumption, which ultimately could improve nutrition in the country. Specific outcomes from this activity include:

- Forty Nigerian aquaculture value chain actors were trained as Lean Subject Matter Experts (LSMEs) and have been certified as effective resources for disseminating the tools.
- Two hundred sixty five smallholder farmers and value chain actors applied Lean principles in their respective workplaces and benefited from improving workplace efficiency.
- The Lean management system, as it applies to aquaculture production, was disseminated to several people using seminars, conferences, workshops, and webinars.
- A Lean systems management training manual and curriculum were developed and applied.
- A RedCap database for continued Lean application data management was developed and applied.
- A general interest in applying Lean principles in workplaces by selected aquaculture communities was created.

Tangible Impacts

- The activity demonstrated that Lean tools contribute to reduction in feed waste, fish mortality, energy consumption costs, labor costs, number of casual laborers employed, medication costs, feed quantity, labor time, water treatment costs, fish loss via flooding, and transportation costs. Furthermore, the activity showed that these reductions are irrespective of gender, scale of operation, farming system, or location in the country.
- The significant improvements observed after the Lean management intervention suggest that the Lean approach has successfully minimized inefficiencies in fish farms in Ogun and Delta states.
- With rare exceptions, all farmers reaped benefits from Lean interventions, regardless of age, sex, geographical location, company status, farm type, farm size, and annual income.

- Findings demonstrate the ability of Lean management practices to help the Nigerian aquaculture sector and individual farmers to drastically reduce waste and become more profitable. This is because Lean management is made of self-applicable tools that depend little on others, are affordable, quickly learned, and easily applied.
- Building a more resilient aquaculture industry in Nigeria requires equipping farmers with the tools to address the myriads of waste within their operations and the supply chain at large. Lean production system has proven to be one such tool.

Activity 1.4: Development of Bighead Catfish (*Clarias macrocephalus*) Culture for Sustainable Aquaculture in Cambodia (Bighead Catfish)

Location: Cambodia

Lead PI: Lyda Hok, PhD, Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture
HC PI: Rodrigue Yossa, PhD, WorldFish
U.S. PI: Manuel (Manny) Reyes, PhD, Kansas State University
U.S. Co-PI: Delbert Gatlin, PhD, Texas A&M University

Objectives: The goal of the activity was to develop and apply new technologies for formulated sustainable feeds for BC (*Clarias macrocephalus*) culture that will increase income, promote gender equality, empower youth, provide nutritious food, and strengthen resilience in Cambodia, while building the capacity of local institutions to expand the farming of this species.
The objectives were

1. To develop and scale cost-effective feeds for sustainable culture of BC in Cambodia.
2. To strengthen the infrastructural and human aquaculture research capacities of local institutions.

Executive Summary: The goal of the Bighead Catfish activity was to develop and apply new aquaculture research technologies to support BC culture in Cambodia. The activity centered around two main investigations, namely the development and scaling of cost-effective feeds for sustainable culture of BC and strengthening the infrastructural and human research capacities of local institutions.

Capacity Building

The activity involved three major training sessions. First, WorldFish trained a PhD student, interns, and the activity team on how to set up a wet lab, operate the recirculating aquaculture system, and maintain it for aquaculture nutrition research at RUA. The operation of the wet lab for scientific research was needed to start the first experiment of the activity at the RUA Aquaculture Farm. Second, two activity members from Cambodia joined a training at WorldFish in Penang, Malaysia, on formulating and producing fish feeds with a pelletizer, stocking samples and harvesting fish in the research facility, collecting and storing fish and feed samples, and managing a recirculating aquaculture system. The third capacity-building exercise was on the operation and maintenance of the fish pelletizing machine to produce floating feed. All the capacity built through these activities has equipped RUA personnel and students in their aquaculture nutrition research, which will benefit Cambodian aquaculture as the industry grows.

Experimental Research

The activity evaluated commercially available feeds with two protein levels for their suitability to support BC culture in Cambodia. The team examined two feed brands from different companies with two levels of protein contents (30% and 35%). They stocked BC at a rate of 30 fish per aquaria for all treatments for 84 days. The result showed that feed brands did not significantly

affect fish growth, FCR, or somatic index. However, feed with 35% protein level improved growth performance and FCR of BC.

The team conducted a second experiment to verify the result of the first experiment in the pond net cages. The team stocked each cage with 30 fish for all treatments and conducted weekly sampling for 14 weeks. This experiment aimed to evaluate the impact of commercially available aquafeed on growth performance of BC.

Recommendations

Based on the results of the activity, the following recommendations are suggested:

- Technical support to a local institution like RUA Faculty of Fisheries and Aquaculture to set up and operate the wet lab facilities is a good initiative to increase aquaculture nutrition research capacity.
- Development of human resources—both short-term and long-term degree trainings—builds a good foundation for the continuation of research on BC.
- The diet consisting of locally available fish feed with 35% crude protein improved growth performance and FCR of BC, providing insights for further studies on optimum feed management.

Lessons Learned

Strong technical support for research design and monitoring for the local researchers and students was critical. Limited local capacity caused some delays in research. However, through this activity, the team built local capacity to conduct aquaculture nutrition research using the wet lab. This will enable better performance of similar research activities in the future.

Due to COVID-19, materials for wet lab installation were not available in Cambodia, which slowed progress on material shipment from Malaysia and wet lab installation. In addition, the process to get permits to export wet lab materials from Malaysia to Cambodia did not progress as planned. Intervention and support from WorldFish Malaysia helped to accelerate the process.

Useable Outcomes

The commercial feed evaluation yielded the following outcomes:

- Feed brand did not significantly affect fish growth, FCR, somatic indexes, proximate composition, and fillet quality.
- Bighead catfish fed diets containing 35% crude protein showed higher growth performance and improved (lower) FCR than those fed diets containing 30% crude protein.
- Feed brand and feed protein content did not affect protein composition in fish fillets, but there were effects on crude fiber and crude fat. However, these did not affect sensory perception tests.

Through collaboration between WorldFish, RUA CE SAIN, and RUA Faculty of Fisheries and Aquaculture, the team set up three main facilities: 1) a wet lab with forty 150-L aquaria mounted in a recirculating aquaculture system (or flow-through system) comprising an air blower, sump, sand or drum filter, bio-filter, UV treatment system, pumps, pipes, and racks, 2) a pond cage system with 16 one-square-meter cages and 1.3 m hapa nets, and 3) a fish feed pelletizing machine (Extruder Model DGP-60), mixer, and grinder to support feed formulation research. The team organized three major training sessions for capacity building as described previously.

The facilities and capacity developed at RUA were used to successfully complete a BC feed

evaluation, which showed that feed with 35% protein significantly improved growth and FCR compared to feed with 30% protein.

Tangible Impacts

Graduate students and undergraduate interns involved will apply and transfer their knowledge on aquaculture nutrition through their teaching, research, and future career paths. The wet lab facilities and pond were installed at the RUA Faculty of Fisheries and Aquaculture and will continue to be used for research and student training as well as demonstrations for commercial farms and farmers.

Activity 1.5: Achieving Coral Reef Fishery Sustainability in the East African Biodiversity and Climate Refugia Center (Coral Reef Fishery Sustainability)

Location: Kenya

Lead and U.S. PI: Timothy McClanahan, PhD, Wildlife Conservation Society
U.S. Co-PI: Nyawira Muthiga, PhD, Wildlife Conservation Society
U.S. Co-PI: Austin Humphries, PhD, University of Rhode Island
HC PI: Emmanuel Mbaru, PhD, Kenya Marine and Fisheries Research Institute

Objectives:

1. Determine the yield potential for coral reef climate refugia to support improved fisheries management.
2. Determine the best metrics for measuring sustainability to enhance the likelihood of sustainable management.
3. Improve the management capacity of communities to monitor fisheries and habitats and use this information for adaptive management.
4. Measure perceptions about natural resource use and sustainability among dependent communities and encourage realistic expectations.

Executive Summary: The activity aimed to address challenges of suboptimal seafood production in a climate refugia in Kenya. Coastal development and promotion of fishing on a national scale could undermine the ability of the poor indigenous coastal communities to sustain their livelihoods and benefit from sustainable fisheries. Small-scale fisheries management and control have been enhanced by Kenya's BMUs over the past decade. Nevertheless, overfishing and lost yields have not been reversed potentially due to poor knowledge of fisheries status or underproduction relative to potential. Among the barriers are destructive fishing gears such as beach seines (long, vertical fishing nets), small-mesh nets, inadequate national and local level cost-benefit sharing, monitoring and subsequent knowledge of the status, weak governance institutions, and associated compliance. This study provided technical information to produce reliable data on fisheries production, effort, catches and their trends, and potential production or sustainable yield goals.

The communities and their landing sites occurred within the international transboundary zone of Kenya and Tanzania planned for transboundary conservation activities. Several climate change studies have identified the area as a high biodiversity climate refuge. Thus, the long-term sustainability will be an important contribution to preservation of coral reefs in the coming decades. There are also numerous economically valuable natural resources and tourist attractions associated with the well-established and successful Kisite-Mpunguti Marine Park and Reserve system. Support for this park system is generally strong but varies among the communities. The fishing grounds within the Mpunguti Marine National Reserve are managed by the Kenya Wildlife Service, while the surrounding waters are under the jurisdiction of the

Kwale County Fisheries Department. Some community fisheries closures (locally called *tengefu*) are managed by the Shimoni, Kibuyuni, Mkwiro, and Wasini BMUs. Seafood consumption by local fisher communities is high and plays an essential role in health through the provision of protein and other micronutrients.

Stakeholder Engagement and Trainings

The activity organized small group meetings and trainings at landing sites. Activities began by testing stakeholder knowledge of the fishing sector, future livelihood preferences, and community needs in the context of feedback sessions to communicate objectives. A baseline household survey estimated wealth, perceptions of the benefits of fisheries restrictions, and the efficacy of informal and formal governance institutions. Surveys were repeated after the intervention activities to measure changes in wealth, governance, and support for fisheries restrictions.

The activity trained high performers on the test on data collection protocols and use of mobile phones. The team compared communities to national government fisheries officers' data in terms of thoroughness of the catch recordings. Additionally, the activity trained fishers in underwater survey methods to estimate the stock biomass of fish in different management zones. Thus, both catch rates and stock biomass training should create the potential for communities to estimate the status of their fishery. In-person training coupled with the development of a Swahili language training manual enabled community data collectors to determine fisheries status. Finally, the team queried fishers' households about their knowledge and perceptions of fisheries laws and alternative livelihood options. These activities created a comprehensive baseline to craft a locally supported fisheries recovery program.

Conclusions and Recommendations

Most stakeholders preferred a future scenario with community and fisheries management programs, while fewer supported offshore fisheries and coastal developments. This varied by community, with those more dependent on natural resources strongly supporting community management while those dependent on trade supported infrastructure development. The scaling of governance institutions and many fisheries restrictions was variable but low during the initial survey. By the end of the study, nearly all governance institutions and fisheries restrictions were scaled higher. The largest changes were some of the more contentious restrictions, such as closures and species restrictions. Household wealth and size increased marginally. Surveys found women had less information, but they also increased their support for restrictions more than men. Nevertheless, demographic metrics, such as gender, youth, household size, and wealth, had considerably smaller influence than the Fish Innovation Lab interventions.

Community members were more effective at measuring catch than equally trained government staff. The community recorded rare and more catches which might be attributed to residing within the community and their commitment to the goal. The team suggests that community measurements of stock be promoted throughout this region, with the caveat that testing of knowledge and training are needed to ensure high-quality data. Results indicated that the fisheries catch or yields from dependent stock assessments were overexploited in all fisheries except for the national marine reserve. Yields declined with distance from park and reserve, with many fisheries underperforming by 1–2 tons/km^2 per year. More discussions and government involvement will be needed to ensure that increased preferences for management restrictions and governance effectiveness are implemented. Given the existing institutional setting in the region and its impact on the sustainability of fisheries stocks in climate refugia in coastal Kenya, short-term priorities to address challenges include supporting the implementation of stronger governance principles of intercommunity and trade conflicts, ecological monitoring or stock assessment, cost-benefit sharing, and fair, consistent, graduated sanctions.

Lessons Learned

Long-term monitoring is needed to inform findings. For example, a long-term dataset is needed to establish recovery rates of fisheries. This implies that plans to sustain ongoing activities should be developed to deliver on activity goals.

A design/plan should be measurable after the life of the activity. For instance, this activity employed surveys before and after implementation. Also, it is critical to identify correct parameters to test as indicators for community well-being and fisheries resources.

Objective experiments are invaluable in decision-making. For example, the team administered exams as a merit-based selection method to identify community members to support the activity's interventions. These exams also provided an opportunity to test compare competency between trained community members and fisheries officers.

Communities can conduct fish landing monitoring and socioeconomic surveys after being trained on protocols. The activity findings showed that community enumerators recorded rare and more samples/surveys.

Useable Outcomes

Stock estimates in the seascape fishing grounds indicated excess effort and predicted maximum sustainable yields at current biomass of 1.8 ± 1.0 tons/km^2/year, which is considerably lower than estimates in other nearby ocean-exposed locations estimated at 5-7 tons/km^2/year. If stocks increase, then this value can increase to 2.9 tons/km^2/year.

The highest yields were captured in the gear-restricted national reserve, where the highest stocks were observed, and declined in relation to park and reserve proximity. This indicated correlated gradients with the location of community and management restrictions, making the two effects difficult to separate.

Low to modest capture rates or fishing will be required to allow the stock recovery needed to achieve sustainability and restoration of the semi-enclosed bay. In general, reducing cumulative impacts will require knowing and managing for local production limits.

Variability and isolation in fisheries rules and governance principles suggest challenges to standardizing and regionalizing management. For example, communities closer to the government park and reserve largely supported fisheries restrictions and the existence of protected areas compared to communities further from the park and reserve. Therefore, standardizing and achieving compliance with these restrictions should be considered a priority to recover overfished stocks. This is likely to require county and national engagement with these communities to build bridging capital and rectify neighborhood conflicts over agreed on management approaches.

Tangible Impacts

Having established low yields and production levels in the seascape, the communities and government initiated conversations during an August 2023 Fishers' Forum meeting on best approaches to reduce fishing effort and increase stocks. The forum, which brought together 250 managers, resource users, and relevant stakeholders, provided a platform for the government research institute, Kenya Wildlife Service, Fisheries Department, and fisher communities to interact. Proposals from the meeting included fish traders avoiding buying fish from fishers using illegal gears and implementation of gear and minimum fish-length restrictions. These initiatives will ensure increased stocks, which provide economically high value catch and nutritional value from more accessible fish.

This activity has set the pace for prescriptive rather than descriptive fisheries management.

Communities demonstrated that they could conduct digital monitoring of their fisheries. This monitoring can be blended in with recommendations to guide fishing communities on their daily, monthly, and yearly catches. This establishes a new level of monitoring and implementation in real-time, which can guide management at community and national levels.

Activity 1.6: Cryogenic Sperm Banking of Indian Major Carps and Exotic Carps for Commercial Seed Production and Brood Banking (Cryogenic Sperm Banking)

Location: Bangladesh

Lead and HC PI: Md. Rafiqul Islam Sarder, PhD, Bangladesh Agricultural University
HC Co-PI: Mohammad Matiur Rahman, PhD, Bangladesh Agricultural University
U.S. PI: Terrence Tiersch, PhD, Louisiana State University

Objectives: The overall objective was to increase production of Indian major carps (IMCs) and exotic carps by improving broodstock quality and seeds through establishing a national genetics program based on cryogenic sperm banking. The specific objectives were

1. To develop donor broodstocks of IMCs and three exotic carps.
2. To cryopreserve sperm of IMCs and exotic carps and develop a cryogenic sperm bank.
3. To produce seeds of carps in hatcheries using cryopreserved sperm and characterize and assess their quality through growth studies and DNA microsatellite analysis.
4. To assess the performance of cryopreserved sperm for establishment of sperm banks in different regions.
5. To evaluate the adoptability of technology by the stakeholders.

Executive Summary: Bangladesh has 260 freshwater and 475 marine fish species, 24 freshwater prawn species, and 36 marine shrimp species. Historically, most fish production came from open water capture fisheries, but due to environmental and man-made activities, production of capture fisheries decreased. Aquaculture started in the early 1980s, and presently about 57% of total fish production (4.76 million metric tons) comes from aquaculture. IMCs such as catla (*Catla catla*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus cirrhosus*) contribute about 32% to aquaculture production, and exotic carps such as silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), and grass carp (*Ctenopharyngodon idella*) contribute about 18% to aquaculture production. This increase in carp production through aquaculture is largely due to production of adequate fish seeds in hatcheries and uninterrupted supply to farmers. Even so, sustainable fish production is not yet a reality in Bangladesh.

Deterioration of IMC and exotic carp seed quality is a factor of high concern for aquaculture production in Bangladesh. Around 984 hatcheries (110 government and 874 private) are involved in seed production through induced spawning, but seed quality deteriorates through inbreeding, hybridization (crossbreeding between two different fish species), and negative selection resulting in slow growth, high mortality, and disease susceptibility of seeds. Consequently, the hatchery and nursery operators and small-scale farmers are shifting to other species like tilapia and catfishes. In fact, many hatcheries have stopped producing carp seeds altogether. To mitigate the issues with carp aquaculture production, the government has initiated a broodstock improvement program for IMCs through establishing live brood banks by rearing river-originated seeds in government hatcheries and distributing broods to other hatcheries. Continuation of the program is difficult because natural seed production is severely reduced, providing less than 1% of the total requirements. Seed quality of exotic carps is also diminishing, and improvement of their broodstocks is challenging as replenishment of stocks is difficult and expensive.

Establishment of a cryogenic sperm bank of IMCs and exotic carps and the use of cryopreserved sperm in seed production in hatcheries are necessary to resolve the existing genetic problems. This technology can also be used to assist the government and private hatcheries to develop brood banks by protecting and providing quality germplasm. Availability of high-quality broodstocks produced by cryopreserved sperm would also increase the capacity of government and private hatchery operators.

Establishing Cryogenic Sperm Banking for Aquaculture Production in Bangladesh

To establish the cryogenic sperm bank, the team first developed a live brood bank of IMCs by rearing Halda and Padma River-originated fish at BAU campus. Similarly, a brood bank of the three exotic carps was developed by rearing fingerlings imported from China by the DoF, and the team collected sperm from the broods for cryopreservation. Beforehand, the team standardized the parameters of the cryopreservation process for all species. The team then conducted breeding using cryopreserved sperm and fresh sperm of hatchery-owned males (control) in 36 selected public and private commercial hatcheries in Mymensingh, Jashore, Faridpur, and Barishal regions, and 28 hatcheries successfully produced seeds. The hatcheries were able to produce seeds of all six species using cryopreserved sperm, but those seeds had lower fertilization and hatching rates compared to control seeds across all the species. Lower fertilization by cryopreserved sperm might have resulted from injuries during the cryopreservation process.

Before seed production, the team conducted a hands-on training on cryopreservation techniques for breeding hatcheries and technology adoption hatcheries in four regions by inviting around 100 stakeholders (in four batches), including hatchery operators and managers, scientists, and regional DoF officials. To compare the growth of cryopreserved- and fresh sperm-originated seeds for quality assessment, the team reared the seeds in 22 breeding hatcheries, four technology adoption hatcheries, and fish farms separately for at least 6 months. Cryopreserved sperm-originated seeds demonstrated a significantly higher growth rate than control seeds in all six species due to introducing quality germplasm through cryopreserved sperm. The inferior quality of hatchery-originated seeds might be due to genetic degradation of hatchery-reared parents. The team used DNA microsatellite markers as another quality assessment tool to determine the parental genetic inheritance of the seeds and found that cryopreserved sperm-originated seeds shared alleles with their parents. To facilitate better adoption, the team arranged 16 technology dissemination workshops (four batches in each region and 25 persons in each batch) for around 400 stakeholders including hatchery and nursery operators, fish farmers, scientists, and NGO personnel. Additionally, the team coordinated a technology dissemination workshop for 50 master’s and PhD students and junior members of the Fisheries Faculty at BAU, and a seminar on fish sperm cryopreservation technology was done for 150 graduate and undergraduate Fisheries students. Research team members also participated in a 2-week-long advanced training at the AGGRC and LSU AgCenter.

Recommendations

This activity resulted in the development of a cryogenic sperm bank of all six species at the BAU laboratory and investigation of the feasibility of establishing cryogenic sperm banks of carps in different regions. The team recommends that this research should be continued to validate the technology and establish sperm repositories for indigenous and exotic carps. With more than one thousand hatcheries distributed throughout the country, government and nongovernment organizations should play a key role in setting up sperm repositories centrally as well as in different carp-dominated areas of the country to provide cryopreserved sperm to hatcheries for quality seed and brood production.

Lessons Learned

1. Reaching all hatchery operators and fish farmers directly by a small research group may not be feasible as more farms and hatcheries adopt cryopreservation production. A better approach will be to train and strengthen capacity in regional centers that can support the hatcheries within a short distance.
2. For convenience, nursery and broodstock ponds should be rented or provide their lease fees to the hatcheries.

Useable Outcomes

1. Cryopreservation protocols of the IMCs and exotic carps were standardized by optimizing the relevant parameters.
2. Cryogenic sperm banks of the six species were developed, and sperm can be used from the bank whenever necessary. Feasibility has been established to set up new sperm banks centrally as well as regionally for the six target species and other commercially important and endangered fish species.
3. Seeds of the six species were produced in public and private hatcheries using cryopreserved sperm. This demonstrated that seeds can be produced using cryopreserved sperm at the hatchery level for developing genetically improved broodstocks.
4. Seeds produced from cryopreserved sperm as well as respective controls (fresh sperm of the hatchery-reared males) were reared separately, and the growth performance of the cryopreserved sperm-originated seeds showed significantly higher growth than the controls. This demonstrated that cryopreservation is an effective tool to produce quality broodstocks by introducing new germplasm through induced breeding.
5. In some hatcheries, broods produced from the cryopreserved sperm in the first year showed better breeding performance, such as high fertilization and hatching rates of eggs and higher rates of seed growth.
6. DoF has planned to set up cryopreservation facilities in their 12 hatcheries where they will cryopreserve and store sperm and distribute the frozen sperm to other hatcheries.
7. Three PhD and at least 11 master's students were directly involved in the activity, and they are a potential human resource to disseminate the technology throughout their future careers. Around 550 stakeholders including hatchery operators, nursery operators, fish farmers, scientists, government officials, NGO personnel, master's and PhD students, and junior faculty members received training on the technology and could apply or disseminate the technology in their respective fields.

Tangible Impacts

1. Better quality seeds were produced using cryopreserved sperm. The seeds will have higher growth and survivability. Thus, hatchery and nursery operators will be able to sell them at a higher price, increasing financial benefits and improving livelihoods.
2. Quality broods can be produced from these cryopreserved sperm-originated seeds. Seeds produced from those broods in the next generation will have higher growth and survivability, contributing to higher rates of production and improved nutrition for consumers.
3. A cryogenic sperm bank that can support future quality brood production programs was established.

Activity 1.7: Increasing Sustainability of Fisheries and Aquaculture for Resilience of Cambodian Communities (Cambodian Fisheries and Food Processing)

Location: Cambodia

Lead and U.S. PI: Sandra Correa, PhD, Mississippi State University
U.S. Co-PI: Wes Neal, PhD, Mississippi State University
U.S. Co-PI: Peter Allen, PhD, Mississippi State University
U.S. Co-PI: Thu Dinh, PhD, Mississippi State University
U.S. Co-PI: Wes Schilling, PhD, Mississippi State University
HC PI: Som Sitha, MS, Wildlife Conservation Society
HC Co-PI: Simon Mahood, PhD, Wildlife Conservation Society

Objectives:

1. Improve sustainable fisheries management by assessing changes in the existing fishery through the development of a protocol to monitor fish populations and implement a citizen science digital platform for documentation and analysis of harvest.
2. Educate and train villagers in standardized food processing and preservation techniques to reduce fish waste.

Executive Summary: Wild fish are a vital resource for human nutrition and commerce in Southeast Asia, but many of these important populations are declining. Government resources are limited and are typically allocated to more valuable fisheries, leaving small-scale rural fisheries unmanaged. Thus, data on fisheries population declines and potential solutions are largely lacking. With the support of Cambodia's Fisheries Administration, local villages along the Sre Ambel River in southern Cambodia have united to provide community-level governance. This arrangement places management authority in the hands of those who have a vested interest in the resource. The activity aimed to improve community resilience and sustainable fisheries management by developing a citizen science program to systematically monitor fish populations, creating an online platform (iFISH: https://ifish.shinyapps.io/ifish) to visualize and interpret data, improving fish protein shelf life by providing education on fish preservation techniques, and conducting nutrient analyses of primary harvested species.

A citizen scientist corps consisting of five villages and 15 fishers was established to collect continuous fisheries data for 2 years. Citizen scientists were provided training, materials, and a small compensation for their time. Oversight, verification, and photographic documentation ensured the accuracy of the data. For each fishing trip, fishers collected data on effort, location, gear, harvest, and size. During the assessment, 162 species were recorded, represented by 118,528 fish with 48,048 individual-level data entries and photos for species and length verification. These data provided a baseline of the river prior to management, will aid in development of management solutions, and will serve as a benchmark to assess the success of and to refine management actions that are implemented. Thus, continuation of the citizen science program is paramount so data are continuous and comparable through time.

<u>iFISH Platform</u>

The activity developed a web-based analysis platform to facilitate visualization and interpretation of fisheries data. A master file containing citizen science data is uploaded to the platform, which then allows the user to visualize the data and make computations as necessary, such as by species, village, season, or gear type. Outputs include catch rates, length frequencies, maps, and other data for management. For example, iFISH demonstrated that fishing grounds by village do not overlap, which will simplify management and enforcement.

Also, only 10 species make up most of the wet season catch, suggesting these species may need to be prioritized. Length frequencies of captured fishes can be compared to maximum lengths to help understand the sustainability of the fisheries. Fish that are harvested at sizes well below maximum length may be subject to overfishing because excessive harvest of fish before they can replace themselves will lead to population declines. Additional evidence on species traits, such as size at maturity, is needed to fully understand these effects. iFISH is open-source software; thus, features like size at maturity can be added as needed.

Fish Preservation Approach

Live fish is the most accepted form for trade at local markets due to the lack of refrigeration. Many fish die before arriving at markets and may go to waste. Preservation of these fish could reduce waste and increase shelf life. The team assessed local fish processing and fish products, designed and trained villagers on minimal processing methods, and produced and further tested processed shelf-stable products. Most fishers reported using ice, salt, or no preservation immediately after harvest, and most (88%) fish were sold whole. Fish not sold immediately were salted (36% of respondents), fermented (29%), dried (25%), and smoked (6%). Consumers demonstrated preferences in species and smoking methods but generally found all preservation products acceptable. Training on fish smoking, fileting, and antimicrobial treatments was provided to villagers, and participants indicated a willingness to continue these practices and join a fish-processing consortium. The research team identified smoking technology using locally available materials (concrete blocks and hardwood) and vinegar treatment for fish preservation as two promising innovations to improve the quality and food safety of local fish as well as the livelihoods of fishers who sell these value-added products.

Nutrient Analyses

Fish species located lower on the food chain (i.e., those who eat plants, algae, or small insects) are more abundant and sustainable than higher-level piscivores (fish that eat other fish), but the nutritional differences are unclear. The team evaluated 11 commonly harvested fish for proximate (protein, fat, water, ash, and carbohydrates) and fatty acid composition. Large-bodied piscivores tended to be slightly higher in protein and lower in fat than small-bodied species, yet differences were insignificant. Conversely, small-bodied species tended to be higher in many important fatty acids, suggesting that the nutritional value of these smaller fishes is at least equivalent to larger piscivores.

Conclusions and Recommendations

This activity created an infrastructure for fisheries data collection, interpretation, and evaluation to improve the management of small-scale fisheries, and it provided outreach on techniques to prolong the shelf life of captured fish. This approach and the iFISH platform are scalable to other artisanal fisheries globally. Based on the results of this activity, the following recommendations are suggested:

- Continue the citizen science program to support adaptability in management.
- Data on life-history characteristics of target fishes (growth patterns, reproduction, etc.) are required for effective management actions.
- Reduce reliance on non-selective gears and reduce or eliminate the harvest of juvenile fishes.
- Spatial variation suggests that management strategies may need to vary by river or village.
- Coordinate a fish processor consortium to continue training in fish preservation methods

and value-added products.

- Harvest fish from lower on the food chain to increase sustainability and provide greater harvest opportunities.
- Target high-value species with better sensory attributes and help fishermen further improve the quality of low-value catches.
- Continue to use digital materials to train fishers on fish processing and preservation.

Lessons Learned

Monthly field visits to fishers participating in the Citizen Science Fisheries Harvest Assessment program proved that good communication and strong participant commitment enable the compilation of robust baseline data. Having a local partner, such as WCS-Cambodia, was instrumental for implementing the program and engaging local participants, given the trust WCS has developed through its long presence in the Sre Ambel region. Local communities are mostly illiterate, which makes engaging them in the citizen science survey difficult. The provision of supplies and equipment by the Fish Innovations Lab was instrumental given the reduced capacity of community fisheries councils, which represented an obstacle to sustainably manage their resources.

Useable Outcomes

- Over the past two years, the Citizen Science Fisheries Harvest Assessment program has collected accurate data on the current status of the Sre Ambel River fisheries, creating baseline information on harvested species, yield per effort, fish size distribution, fishing gear selectivity, fishing zones, and distance traveled.
- Based on activity results, many fish species are potentially being harvested at sizes that do not allow reproduction. Regulations to set minimum sizes allowed to be harvested and/or gear restrictions to reduce non-selecting catch or allow smaller fish to escape should be considered.
- Inexpensive preservation methods to bring fish ashore were identified, and buffered vinegar is a promising approach because it does not affect sensory attributes and was effective.
- A smoking method and device to increase the value of fish was developed, and fishermen can easily build one that fits their needs.
- Crucial information on fish size and nutritional composition is now available to inform approaches to manage harvest and improve preservation. Preferred cooking methods are also known, which allows for better fish consumption in Cambodian households.
- A collection of video clips is available for further training beyond the life of the activity.

Tangible Impacts

Workshops on fisheries management directed to community fisheries members participating in the Citizen Science Fisheries Harvest Assessment program allowed the team to share the results of the data the fishers collected. By participating in the Citizen Science program, community fisheries members interacted with graduate students, NGO staff, Cambodian fisheries administrators, and fishers from another province that have an ongoing community-based fisheries management program. These experiences, the training, and the materials received prepare them to continue the Citizen Science Fisheries Harvest Assessment data collection program and implement community-based management in the Sre Ambel River, enhancing the resilience and livelihoods of local fishing communities.

Having community fisheries members visit other communities to learn about successful fisheries conservation is a good approach that is inspiring them to do the same.

A clear understanding of species, sensory preference, and processing methods can now facilitate targeted harvest and value addition to low-value (low sensory acceptability) catches.

Activity 1.8: Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement (Carp Genetic Improvement)

Location: Bangladesh

Lead PI: Matthew Hamilton, PhD, WorldFish
Lead Co-PI: John Benzie, PhD, WorldFish
HC PI: Mohammed Yeasin, WorldFish
HC Co-PI: Mostafa Hossain, PhD, Bangladesh Agricultural University
U.S. PI: Terrence Tiersch, PhD, Louisiana State University Agricultural Center

Objectives:

1. Ensure capacity in private hatcheries and nurseries for business plan implementation and commercial delivery of improved carps.
2. Conduct assessments of farm performance of genetically improved carps, providing data to strengthen marketing and business analysis.
3. Secure and genetically improve core populations of rohu, catla, and silver carp and develop and apply tools for genetic management of these three species that can be operated under a commercially oriented model of carp genetic improvement and dissemination in Bangladesh.

Executive Summary: This activity aimed to produce new generations of improved carp in Bangladesh—catla (*Catla catla*), rohu (*Labeo rohita*), and silver carp (*Hypophthalmichthys molitrix*)—building on genetic improvement programs managed by WorldFish. The activity aimed to produce a cryopreserved sperm repository strategy, disseminate additional genetically improved carp, assess the on-farm performance of G3 genetically improved rohu, develop a cost-effective pedigree assignment tool, and undertake training activities.

<u>New Generations of Improved Carp</u>

The activity produced G3 rohu (228 families), generation two (G2) silver carp (240 families), and generation one (G1) catla (203 families). The team produced and maintained a selection line (families selected for rapid growth), a control line (genetically equivalent to unimproved base populations), and a negatively selected line (to be used in future research to identify genes affecting growth) for each species. Representative fish from each of these populations were subsequently shipped to two geographically distant sites to be maintained as backup populations. The team anticipates that each new generation of selection lines will grow approximately 10% more rapidly than the previous generation, with positive impacts on pond productivity, farmer incomes, and fish availability in the market.

<u>Dissemination of Additional Genetically Improved Carp</u>

The activity supplied private- and government-owned hatcheries with G3 rohu hatchlings (i.e., the “G3 rohu multiplier”) to be grown into broodstock in 2021 and 2023. At the conclusion of the activity, 38 geographically disparate private, 18 DoF, one BFRI, and two educational institution hatcheries were known to maintain G3 rohu broodstock.

Commercial hatcheries spawned G3 rohu for the first time in 2022. Over that spawning season, seven commercial hatcheries produced 245 kg of spawn. The hatcheries sold spawn produced

in 2022 to 65 farmers and 104 nurseries. By the conclusion of the activity, these 104 nurseries had sold seed to approximately 3,000 farmers.

In early 2023, production of G3 rohu spawn by 13 hatcheries grew to 2,826 kg. Assuming 15 farmers are supplied for each kg of spawn produced (as in 2022), the research team expected 42,390 farmers to use G3 rohu spawn in 2023. The team anticipates that G3 rohu spawn production will increase in 2024 and beyond as demand for the product increases.

On-Farm Performance of G3 Rohu

To compare the on-farm performance of the G3 rohu population disseminated to hatcheries (i.e., the "G3 rohu multiplier") against fish from the WorldFish control line and a well-regarded commercial strain, the team tagged fish and distributed them for grow-out on 19 semi-commercial farms across two Bangladeshi regions (Jashore and Natore–Rajshahi). At harvest, the G3 multiplier weighed approximately 37% more, on average, than the unimproved control and substantially outperformed both the control and commercial strain on all 19 farms.

Training Activities

The team organized two hatchery training workshops, which aimed to improve knowledge of genetics and the management and marketing of genetically improved carp. Sixty men and eight women attended the workshops, and the team provided a manual to all participants that is also available online in Bangla and English.

Cryopreserved Sperm Repository Strategy

In addition to maintaining backup populations in ponds, the activity developed a cryopreserved sperm repository strategy. Germplasm repositories allow storage of sperm for long periods and are unaffected by disease or natural disasters.

Pedigree Assignment Tool

The activity also developed a pedigree assignment tool to test carp DNA to determine the purity of genetically improved strains. For rohu, the team identified a panel of 118 SNPs, or variations at specific positions in the DNA sequence among individuals. However, accurate parentage assignment (to determine purity of the G3 rohu) using this panel was not possible because a high proportion of SNPs were considered rare variants. For catla, the team developed a larger panel, comprised of 486 SNPs with a high proportion of more common variants. The team anticipates that this panel will allow accurate and routine application of parentage assignment in this species.

Conclusion and Recommendations

The team recommends the following:

- Continue to engage and monitor private- and public-sector parties involved in G3 rohu dissemination to a) inform future dissemination practices, and b) facilitate the development of research and dissemination partnerships to sustain carp genetic improvement over the long term.
- Undertake research into a) intensive nursing practices to facilitate consolidation in the nursery sector and commercialization of carp genetic improvement; b) mono-sex production, or production of all male or all female populations, for partial intellectual property protection and improved productivity/profitability; c) additional traits (e.g., disease resistance, feed conversion, resilience); and d) interactions between genetic and environmental factors.
- Develop SNP panels, akin to that developed for catla, for all species to allow a)

parentage assignment and communal early rearing; b) sex determination; and c) distinguishing between genetically improved and genetically unimproved populations. In addition, pursue tools required to implement genomic selection.

- Encourage the development of private carp pathogen screening services in Bangladesh.
- Consider the genetic improvement of additional species (e.g., mrigal; *Cirrhinus cirrhosus*) and implementation of the cryopreservation strategy.

Lessons Learned

The team noted that they should have been more conservative in their initial impacts relating to the dissemination of G3 spawn via commercial hatcheries. Asking hatchery owners about their expected levels of production is not a good approach to estimating this because they are prone to substantially overstating their levels of future production.

Useable Outcomes

- Genetically improved G3 rohu was sold by seven commercial hatcheries for the first time in 2022. Trial results were published as a peer-reviewed paper.
- G3 rohu spawned in 2022 (245 kg) were purchased by approximately 3,017 farmers and are currently being grown out. An additional 2,826 kg of spawn was sold by hatcheries in 2023.
- On-farm trials indicated that G3 rohu grew approximately 37% more rapidly than unimproved rohu.
- At the conclusion of the activity, 38 geographically disparate private, 18 DoF, one BFRI, and two educational institution hatcheries were known to maintain G3 rohu broodstock.
- Training for hatchery owners and an associated manual (published online in Bangla and English) improved understanding of genetics and strengthened marketing and business decision-making in the sector.

Tangible Impacts

- The improved growth rate of G3 rohu will positively impact pond productivity on these farms, increase farmers' incomes, and increase the supply of fish.
- As a result of this activity, the supply of G3 rohu will increase in 2023 and beyond.
- Over the longer term, genetic gains achieved in rohu, catla, and silver carp breeding populations through the activity will be disseminated to the benefit of hatcheries, nurseries, farmers, and consumers.

Closed Activity: Piloting Integrated Insect-to-Fish Farming Systems in Malawi (Black Soldier Fly in Malawi)

Location: Malawi

Lead and U.S. PI: Jennifer L. Pechal, PhD, Michigan State University
U.S. Co-PI: Simone Valle de Souza, PhD, Michigan State University
U.S. Co-PI: Marjatta Eilittä, MS, PhD, Cultivating New Frontiers in Agriculture
HC PI: Jeremiah Kang'ombe, PhD, Lilongwe University of Agriculture and Natural Resources
HC Co-PI: Ari Magnus Mathiesen, LM Aquaculture Limited

Objectives: The activity aimed to couple work with small- and medium-scale farmers, a medium- scale fish farmer, and BSF producers (targeting female and youth producers) to

conduct experiments that evaluate:

1. Costs and conversion ratio of propagating BSF and processing into aquaculture feed.
2. Feasibility and cost-effectiveness of waste streams (spent grain, market waste) for BSF farming.
3. Changes in pond yield and productivity resulting from different mixes of BSF meal in fish feed.
4. Existing aquaculture value chains and potential income gains from increased aquaculture cost-efficiency.

Executive Summary: BSF farming represents a viable option for enhancing productivity of aquaculture value chains in Malawi. This activity's focus on fish feed production aimed to integrate efforts to promote smaller scale BSF production (targeting small- and medium-scale fish farmers) with BSF production advancing larger scale production in Africa. Key parameters, such as optimal BSF- suitable waste streams, feed ratios, cost-effectiveness for fishmeal replacement ratios, potential effects on fish production yield, and value-chain linkages between BSF and aquaculture production have not been tested in the field for small- and medium-scale producers in Feed the Future target and aligned countries. The goal of this activity was to fill the empirical knowledge gaps that currently preclude effective implementation of BSF as affordable aquaculture feed in sustainable, nutrition-sensitive aquaculture value chains, while developing a network to expand knowledge dissemination and collaborative partnerships from small- to large-scale BSF production to benefit fish sectors.

Lessons Learned

Despite continuous efforts from the ME to support the team, the Piloting for Integrated Insect-to-Fish Farming activity in Malawi was not able to start activities in a timely manner; as a result, goals could not be achieved in the remaining time frame. Therefore, the activity was closed. Because this activity did not achieve results, it is not counted in the total number of Fish Innovation Lab Phase 1 activities, and Malawi is not counted as a country of implementation.

Objective 2: Reduce and Mitigate Risks to Aquaculture and Fisheries

Activity 2.1: Improving Biosecurity: A Science-Based Approach to Manage Fish Disease Risks and Increase the Socioeconomic Contribution of the Nigerian Catfish and Tilapia Industries (Improving Biosecurity)

Location: Nigeria

Lead PI: Mohan Chadag, PhD, WorldFish
Lead Co-PI: Jerome Delamare-Debouttеville, PhD, WorldFish
Lead Co-PI: Rohana Subasinghe, PhD, WorldFish
U.S. PI: Larry Hanson, PhD, Mississippi State University
U.S. Co-PI: Robert Wills, PhD, Mississippi State University
HC PI: Olanike K. Adeyemo, DVM, PhD, University of Ibadan
HC Co-PI: Oluwasanmi O. Aina, DVM, PhD, University of Ibadan
HC Co-PI: Selim Alarape, DVM, MVPH, University of Ibadan

Objectives:

1. Understand epidemiology and health economics of catfish and tilapia aquaculture in Ogun and Delta States, Nigeria.
2. Understand health status of catfish and tilapia in a regional model by employing

presumptive field and laboratory diagnostics.

3. Identify pathogens of economic significance circulating in Nigerian catfish and tilapia aquaculture using whole genome sequencing.
4. Develop better management practices and build capacity to reduce risks of disease outbreaks in catfish and tilapia aquaculture in Nigeria.
5. Develop science-based policies and strategies for reducing fish disease risks in Nigerian aquaculture for longer-term development beyond the three years of the activity.

Executive Summary: Nigeria is currently one of Africa's largest aquaculture producers, and catfish and tilapia are the most farmed fish. However, the lack of a clear aquatic animal health strategy has resulted in substantial disease-related production losses. The Improving Biosecurity activity in Nigeria aimed to better understand the disease and health status of aquaculture through deployment of a digital epidemiology survey, collection and laboratory analyses of biological samples, and a series of stakeholder consultations. By identifying key risk factors and farm-level biosecurity gaps, the activity sought to develop recommendations on better management practices for farmers and action points for the national authorities. The activity was implemented by WorldFish in Malaysia together with MSU in the U.S. and UI in Nigeria.

Results

To better understand existing biosecurity management practices and risk factors that could potentially lead to mortality and production losses in catfish production systems, the research team developed a Fish Epidemiology and Health Economics digital survey tool to collect baseline data from 399 farms in Delta and Ogun States. Fish samples were also collected from farms that were recruited for the epidemiological study. The samples underwent bacterial identification, DNA extraction, biochemical testing, and antibiotic susceptibility tests. The findings were presented in two master's theses, two scientific publications, and a detailed microbiology report.

Better Management Practice Guidelines

Epidemiological analyses of the data set from 399 farms helped to identify several risk factors and biosecurity gaps in local production systems. These results were shared with key stakeholders from both states, including farmers, farm cluster leaders, government officers, academic institutions, and resident veterinarians, as part of a workshop held in August 2022 in Oyo, Nigeria. Insights from the workshop and lessons learned from the researchers and farmers throughout the field survey were then used to create a better management practices manual to address the identified risks. The manual provided general guidelines to establish and maintain biosecurity practices for aquaculture farms in the Nigerian context. Workshop participants also brainstormed key components for a National Aquatic Animal Health Strategy, which Nigeria does not currently have, and minimum operational requirements for such a strategy.

Poor communication between fish farmers and resident veterinarians emerged as a key gap in fish health management through this activity. The research team identified and engaged resident aquatic veterinarians in Ogun and Delta States to assist farmers in disease diagnosis and treatment of sick fish as well as maintenance of standard biosecurity on their farms. The team also created E-AquaHealth (https://ohrg-unibadan.org/aquahealth/), a web-based platform to bridge the gap between fish farmers and aquatic veterinary professionals to enhance the delivery of quality services and improve the wellbeing of fish.

Conclusions and Recommendations

The Improving Biosecurity team built a large data set on farming practices and farmer behavior

from 399 catfish farmers in Nigeria using their online digital tool. This led to the identification of several risk factors associated with unusual mortality events and farm-level biosecurity gaps. Microbiological findings highlighted the need for a One Health approach in managing bacterial diseases and use of antimicrobial agents. Extensive use and abuse of antimicrobials in the aquaculture industry was established, and AMR genes were identified through next generation DNA sequencing. Potential risk of environmental bacteria (e.g., *Klebsiella*, *Salmonella*, and *Pseudomonas* spp.) to human health was also identified.

It is evident that aquatic animal diseases and One Health issues are influenced by various actors and elements involved in aquatic food systems and beyond. Hence, advocating for collective action under a One Health framework is necessary to promote responsible and sustainable aquatic food systems in Nigeria. The following recommendations will contribute to the long-term sustainability of findings and benefits from this activity:

- Publish the epidemiology study report on an open-access platform to motivate and encourage researchers in Africa and Asia to undertake more epidemiological studies, fostering knowledge sharing and advancing the field.
- Promote the epidemiology survey tool to provide valuable insights into farmer behaviors, production practices, outcomes, mortality events, and socioeconomic factors. Analyzing this data can help identify trends, associations, and risk factors, informing the development of interventions in the form of better management practices and farm-level biosecurity plans. (Aquatic Animal Health Package of Practices: Fish epidemiology and health economics—https://hdl.handle.net/20.500.12348/4900)
- Promote better management practice guidelines amongst farm clusters and utilize them to train government extension workers, resident veterinarians, and university students. This will enhance the adoption of sustainable and responsible practices within the aquaculture sector.
- Promote the E-AquaHealth platform by leveraging the skills and resources of UI, resident veterinarians, and the farmer cluster network. The E-AquaHealth platform can offer diagnostic services to farmers in Nigeria, providing timely and accurate disease diagnosis and aiding in effective disease management.
- Promote the use of e-learning modules and standard operating procedures developed by the activity as educational and teaching materials in universities and extension units to enhance knowledge dissemination and capacity building. These resources are available at https://ohrg-unibadan.org/aquahealth/vetsupport/articles.
- Promote the National Aquatic Animal Health Strategy draft document through the National Competent Authority platform to help raise awareness among policymakers and stakeholders and facilitate the operationalization of a national strategy.

Implementing these recommendations can foster collaboration, knowledge sharing, and capacity building, leading to improved aquatic animal health, biosecurity governance, and the development of sustainable aquaculture systems in Nigeria.

Lessons Learned

Beginning with the conceptualization of an activity, all partners should identify their strengths and weaknesses, which can then be addressed appropriately during project implementation. Initiating the technical aspects of the work as soon as possible is very important because it can help the team adjust to any shortcomings during the first few months. For activities such as this, adjusting once the work is underway is more challenging. The team learned the importance of leveraging access to other institutions in the country, such as IITA for some laboratory analyses.

It would have been beneficial for team members to have opportunities to travel and interact with other experts within UI.

Awareness of other research investments, such as the Fleming Fund country grant on topics including One Health, AMR, and genetic sequencing capacity, can help USAID and other donors leverage investments for greater impact and scale.

A platform to connect team members across Fish Innovation Lab activities could be beneficial and enable efficient, cost-effective sharing of knowledge and expertise.

Useable Outcomes

1. A comprehensive dataset on farming practices and farmer behavior was created from 399 catfish farmers in Nigeria using an online digital epidemiological tool. This dataset was analyzed using specialized epidemiological software, allowing the team to identify several risk factors associated with unusual mortality events in catfish farms, along with significant gaps in farm-level biosecurity practices.
2. Extensive biological sampling was conducted from farms experiencing mortality events, allowing the team to identify key environmental and fish-associated bacterial pathogens.
3. The activity employed next generation sequencing techniques to validate and compare the conventional bacterial identification methods, enhancing the accuracy and reliability of the results.
4. National workshops on better management practices and a National Aquatic Animal Health Strategy were conducted in Nigeria in August 2022. These workshops provided key insights into the identified gaps at the farm and national levels and outlined possible ways forward.
5. To support farmers, practicing aquatic veterinarians, and extension workers, the activity created the E-AquaHealth platform (https://ohrg-unibadan.org/aquahealth) at UI.
6. The team conducted a practical training program, enhancing the capabilities of researchers in the field of molecular diagnostics and fish health management in their respective countries.
7. The team developed a documentary to communicate their findings and promote sustainable aquaculture development in Nigeria (https://youtu.be/jDgQ3vLrFo4).

Tangible Impacts

1. The study highlighted the extensive use and misuse of antimicrobials in the aquaculture industry and identified antimicrobial resistance genes associated with bacterial isolates.
2. The team identified environmental bacteria with potential risk to human health, such as *Klebsiella*, *Salmonella*, and *Pseudomonas* spp., emphasizing the importance of a One Health perspective.
3. All microbiological findings from the study were summarized in four abstracts, forming part of post-graduate research at UI.
4. The findings from the epidemiological study were used to formulate draft better management practices and farm-level biosecurity plans for use by the aquaculture industry, promoting sustainable and responsible practices.
5. Action points were identified for the development of the National Aquatic Animal Health Strategy to support the national competent authorities, and a draft document was produced.

6. The team identified needs for cross-sectoral capacity development, focusing on evidence use and laboratory upgrading, to better support the industry.
7. The activity established a network comprising of farmers, cluster leaders, resident veterinarians, and university researchers, fostering collaboration and knowledge sharing.
8. The activity developed and published a resilience model, providing a framework for enhancing the resilience of the aquaculture sector in Nigeria.
9. A list of recommendations was developed (listed above in Conclusions and Recommendations). With adoption and scaling, long-term impacts in the areas of fish production, nutrition, fish consumption, livelihoods, and aquaculture production can be realized to promote responsible and sustainable aquatic food systems in Nigeria.

Activity 2.2: Identifying the Major Sources of Foodborne Pathogens in Bangladeshi Aquaculture Value Chains and the Most Cost-Effective Risk Reduction Strategies (Foodborne Pathogens)

Location: Bangladesh

Lead and U.S. PI: Mohammad Aminul Islam, PhD, Washington State University
U.S. Co-PI: Clare Narrod, PhD, University of Maryland
U.S. Co-PI: Salina Parveen, PhD, University of Maryland Eastern Shore
HC PI: Mohammed Badrul Amin, PhD, International Centre for Diarrheal Disease Research, Bangladesh

Objectives:

1. Determine the prevalence of pathogens on pangas catfish and tilapia at retail markets.
2. Understand behavioral practices of fish value-chain actors that can impact microbial contamination of fish.
3. Assess the fish value chain for microbial contamination and develop quantitative microbial risk assessment models characterizing exposure to pathogens along the fish value chain.
4. Conduct sensitivity analysis using quantitative microbial risk assessment models to identify critical points for implementing future intervention strategies.

Executive Summary:

Food Safety Challenges in the Aquaculture Supply Chain in Bangladesh

Over the past decade, Bangladesh has witnessed remarkable progress in aquaculture production. The cultivation of tilapia (*Oreochromis niloticus*) and pangas (*Pangasius pangasius*) holds significant commercial importance in the country. While the aquaculture industry has experienced substantial growth through intensive farming methods, there has been limited focus on improving fish safety concerning contamination with human pathogens, including multi-drug resistant organisms. The activity assessed contamination of tilapia (*Oreochromis niloticus*) and pangas (*Pangasius pangasius*) with *E. coli* and antibiotic-resistant *E. coli* along with major foodborne pathogens (*Salmonella* spp., *Shigella* spp., *Vibrio cholerae*, *Vibrio parahaemolyticus,* and *Cryptosporidium* spp.) throughout the supply chain, from fish farmers to the cut-up tables in retail markets.

Cut Fish in Retail Wet Markets Have High Levels of Microbial Contamination

The research team found that 92% of cut-fish samples from retail markets in Dhaka City were contaminated with *E. coli*. However, the prevalence of *E. coli* was significantly higher in samples

from wet markets (97%) compared to super shops (grocery stores) (71%). Similarly, a significantly higher proportion of wet market samples (58%) were positive for extended spectrum beta-lactamase producing *E. coli* (ESBL-Ec) compared to samples from super shops (8%). The prevalence of *Salmonella* spp. was significantly higher in wet market samples (28%) compared to samples from super shops (8%). The prevalence of contamination was not related to a fish vendor's business hours as no significant difference was observed in the prevalence of *E. coli*, ESBL-Ec, *V. cholerae*, and *Salmonella* spp. between fish samples collected during the morning and evening hours.

The level and type of foodborne pathogens varied between tilapia and pangas. The concentrations of both *E. coli* and ESBL-Ec were significantly higher in pangas compared to tilapia. In contrast, a significantly higher number of tilapia samples was positive for *Salmonella* spp. compared to pangas.

Fish Processing in Unhygienic Conditions in Wet Markets Contributes to Contamination of Fish

In this study, 66% of fish farmers reported using antibiotics directly in their ponds, and a concerning 92% of these farmers purchased antibiotics without any prescription. The hygiene practices of cut-up table workers in the wet markets were suboptimal. About 44% of these workers reported using only water to wash their hands, cutting board surfaces, knives, and other apparatus. None of the cutting stations had running water, and the cut-up table workers reused the same water repeatedly for handwashing and washing scaled fish, rarely using soap or detergent during cleaning.

In the wet markets, over 70% of cutting board swab samples tested positive for *E. coli*, ESBL-Ec, and *Vibrio cholerae*, and 40% of samples were positive for *Salmonella* spp. Comparison of the prevalence of ESBL-Ec between whole fish samples from vendors and cut-fish samples from the cut-up tables in the same wet markets showed that the prevalence of ESBL-Ec in cut-fish samples (58%) was significantly higher than the whole fish samples (20%). These findings suggest that external sources of contamination during fish processing may contribute to increased prevalence and abundance of ESBL-Ec in cut-fish samples in wet markets.

Risk Assessment Can Guide Implementation of Intervention Strategies to Improve Microbiological Safety of Fish

Risk modeling with the data collected from the fish supply chain identified that the highest level of microbial contamination occurs in the wet markets, especially at the fish cut-up points. The fish cutting board was most frequently contaminated. The research team believes that an intervention at the cut-up tables in retail markets would reduce pathogen loads in ready-to-deliver fish to consumers.

Why is it Important to Reduce the Microbial Contamination of Raw Fish Although Bangladeshis Do Not Eat Raw Fish?

The study revealed that fish from retail markets had high levels of contamination with foodborne pathogens. Individuals who handle contaminated fish without taking preventive measures are at risk of exposure to these pathogens. Additionally, raw fish can potentially contaminate cooked food in consumers' households, leading to foodborne infections, particularly diarrhea. These infections are highly prevalent in Bangladesh, especially among children under five years of age, who often experience numerous episodes of diarrhea before their first birthday. Repeated episodes of diarrhea can damage the intestinal epithelial layers, resulting in reduced nutrient absorption, known as environmental enteropathy. This condition puts children at high risk of malnutrition, which, in turn, increases their vulnerability to diarrhea, creating a vicious cycle. Reducing the contamination levels of harmful microbial pathogens in raw fish at the retail market would lower the exposure to these organisms at the household level, resulting in a positive

impact on consumers' health.

Recommendations

The research conducted under this activity identified some critical behaviors and practices among actors along the supply chain that can be targeted for future intervention studies, including the following:

- Reduce unnecessary use of antibiotics in the pond at the production level.
- Improve hygienic practices of cut-up table workers in the wet markets and ensure supply of clean water for processing of fish.
- Consumers should use separate bags for purchased fish and process them at home following proper hygiene practices to avoid cross-transmission.

Lessons Learned

The activity could not address gender equity in the project. Reasons include limited participation of women in the fish supply chain and the fact that the activity only targeted retail markets in Dhaka. Expanding the scope of work to other districts in Bangladesh could have led to inclusion of female stakeholders, however this was limited by budget constraints.

One of the important aspects of food safety risk assessment is dietary exposure to targeted foodborne pathogens through the consumption of contaminated food. This activity did not survey consumers' practices and dietary patterns at the household level to collect relevant data to plug into the risk assessment framework. A more detailed consumer survey covering the areas of food safety, nutrition, and water, sanitation, and hygiene (WASH) aspects would be needed for future risk assessment efforts.

The activity did not collect comprehensive data on antibiotic use in the growers' ponds and test the fish samples for antibiotic residues. This data would be very useful for explaining the relationship between antibiotic use and AMR.

One of the concerns that emerged while analyzing the data was whether fish that are heavily contaminated with *E. coli* and other foodborne pathogens have the same nutritional content as fish that are less contaminated. Testing a subset of fish samples with a high and low level of contamination for micro- and macronutrients would be useful.

During the Fish Innovation Lab's Bangladesh Sector Meeting in Mymensingh in FY22, stakeholders provided feedback on the term "fecal pathogen" used in the activity. Although this is a widely used scientific term, it may create a negative impression among consumers on the quality of fish at retail markets. The team decided to use "fecal pathogen" for scientific publications and "foodborne pathogens" for communicating with stakeholders and the general public.

Useable Outcomes

The following findings can inform evidence-based interventions and policies to reduce foodborne pathogen contamination of fish and increase the availability of safe, nutritious fish for consumers:

1. Both cut-up pangas and tilapia in the retail wet markets in Dhaka City were highly contaminated with *E. coli* and *Salmonella* spp. including multi-drug resistant organisms.
2. Microbiological contamination of cut fish was significantly higher than whole fish samples from vendors in the retail wet markets.
3. The frequency and level of microbial contamination of fish in wet markets were

significantly higher than fish from super shops.

4. The prevalence of *E. coli, V. cholerae*, and *Salmonella* spp. was significantly higher in both tilapia and pangas in the retail markets compared to wholesale markets and growers' ponds.
5. More than 70% of cutting-board swab samples at retail markets were positive for ESBL-Ec and *V. cholerae*, and 40% were positive for *Salmonella* spp.
6. Lack of proper infrastructure in the market and unhygienic practices of cut-up table workers during fish processing in retail markets contributed to high levels of contamination of fish with foodborne bacterial pathogens.
7. Around 66% of the farmers interviewed in the study reported using antibiotics in their ponds, and 92% of farmers reported using antibiotics without a prescription.
8. The high prevalence of microbial pathogens and unhygienic practices by supply-chain actors implied poor knowledge and infrastructure for postharvest management in aquaculture.

Tangible Impacts

This study presented an analysis of microbial pathogens in the fish supply chain from producers to consumers. The researchers closely monitored the changes in microbial contamination throughout the entire supply chain and identified retail markets as a critical point of contamination. The study emphasized the significance of maintaining proper hygiene practices such as cleaning hands and cutting surfaces and the use of safe and clean water. The findings suggest the need for a controlled intervention study evaluating the impact of sanitizing cutting tables prior to the handoff of fish to consumers. An unanticipated finding from the study was the presence of multiple antibiotic-resistant pathogens in the fish supply chain, which highlights the need for the aquaculture sector to ensure standard practices are followed by all actors in the supply chain. The study also collected data/evidence that can be used in the future to sensitize value-chain participants about the potential microbial hazards resulting from unhygienic practices. This knowledge can support efforts to raise awareness among different stakeholders through interventions to adopt more hygienic approaches, ensuring the safety and quality of the fish supply. The Bangladesh Food Safety Authority acknowledged the study findings positively, as they provided valuable evidence for the need to initiate preventive measures at the market level. By using the evidence and acting upon the study's recommendations, the authority can better implement policies and interventions that will likely, if implemented correctly, safeguard consumers' health and maintain the safety of fish products in the market.

Activity 2.3: Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia (Vaccines for Tilapia)

Location: Zambia

Lead and HC PI: Bernard Mudenda Hang`ombe, BVM, MS, PhD, University of Zambia
U.S. PI: Stephen Reichley, DVM, PhD, Mississippi State University
HC Co-PI: John Yabe, BVM, MS, PhD, University of Zambia
HC Co-PI: Mwansa Songe, BVM, MS, PhD, Central Veterinary Research Institute
HC Co-PI: Patricia Bwalya, PhD, Zambia Ministry of Fisheries and Livestock

Objectives:

1. Identify *Lactococcus garviae, Streptococcus iniae, Streptococcus agalactiae, Aeromonas hydrophila*, and/or *Aeromonas veronii* associated with fish mortalities in aquaculture establishments of Lake Kariba.

2. Confirm pathogenicity and disease causation through development of experimental infection methods in tilapia.
3. Develop and test autogenous vaccines for *L. garviae*, *S. iniae*, and/or *S. agalactiae*.
4. Devise methods of administering autogenous vaccines to the fish on farms.
5. Improve the administration of the already developed *L. garviae* vaccine through various methods.

Executive Summary:

Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia

Africa has seen a rapid increase in aquaculture production, with a large share occurring in Zambia as the country has intensified its political and economic support to the industry. The intensification has led to increased disease occurrences that have affected productivity in both large- and small-scale establishments. Small-scale establishments are severely hit in some cases as producers lack technical know-how to prevent and respond to disease outbreaks. The aim of the activity was to identify bacteria causing disease in small-scale aquaculture establishments and develop an autogenous vaccine for the farmers. Following vaccine formulation, the research team also investigated methods of improving vaccine administration.

Bacteria Identification and Disease Causation

Bacteria involved in fish mortalities were identified from small-scale farmers who had stocked fish in cages with a capacity of 25,000 fish. The sick fish were sampled, and bacteria were identified using the analytical profile index and genetic sequencing. The identified bacteria genera included *Acinetobacter*, *Pseudomonas*, *Aeromonas*, *Bacillus*, *Clostridium*, *Klebsiella*, *Lactococcus*, *Micrococcus*, *Staphylococcus*, *Streptococcus*, and *Vibrio*. Of these bacteria identified, *Acinetobacte*r, *Aeromonas*, *Klebsiella*, and *Lactococcus* were documented as pathogenic after testing in fish.

Development and Testing of the Autogenous Vaccine

Of the identified bacteria, *Lactococcus garviae* and *Aeromonas hydrophila* were selected for vaccine formulation following their pathogenic potential. These bacteria were killed and tested for vaccine efficacy using two exposure methods: injection and bath immersion. The killed *Lactococcus garviae* vaccine administered through the injection route provided good protection; no clinical signs were observed in the vaccinated fish as opposed to the control groups. The killed *Aeromonas hydrophila* vaccine provided some protection using the injection exposure route. Protection provided by the immersion route was low for both vaccines, with protection being better for *Lactococcus garviae* compared to *Aeromonas hydrophila*. The *Lactococcus garviae* vaccine was used in field trials at a farm. At the end of the activity, deaths were not recorded in the vaccinated cage as compared to the unvaccinated cages.

Conclusions and Recommendations

This study revealed the potential use of autogenous vaccination in minimizing losses in aquaculture that may emerge from production diseases in Zambia. In this study, known opportunistic fish pathogens were identified such as *Lactococcus garviae*, *Aeromonas hydrophila*, *Klebsiella*, and *Vibrio*. The isolation of *Klebsiella* highlighted the potential presence of human fecal contamination in water. Holistically, the study demonstrated that vaccination can be an effective part of an aquatic animal health program for the country.

Based on observations and interactions with the farmers, the following recommendations are proposed:

- Continue studies on autogenous vaccine formulation and application in the field for the benefit of farmers.
- Improve biosecurity and aquatic health knowledge and extension by the Ministry of Fisheries and Livestock.
- Move to a more proactive approach of evidence-based strategies for the prevention and control of aquatic diseases in the country and region where there are shared water bodies.
- Build confidence and trust with farmers for successful knowledge uptake and change in farm practices by the various stakeholders involved in the industry.
- Create secured platforms for collection and storage of data through UNZA and Ministry of Fisheries and Livestock that farmers can and are willing to use.
- Develop communication channels on social media platforms for farmers to obtain early outbreak reports for sample collection and disease diagnosis by UNZA and Ministry of Fisheries and Livestock.

Lessons Learned

While collecting fish samples from the cages owned by small-scale farmers, the team observed a lack of knowledge on fish health and biosecurity. There were virtually no signs of disease prevention measures being enforced. The farmers had no knowledge of fish movement restrictions, limiting access to the production site, or sanitation and disinfection procedures. An initial assessment of their knowledge and understanding of fish health and biosecurity could help inform implementation strategies.

Useable Outcomes

1. The team shared fish health management techniques for disease prevention and biosecurity with small-scale fish farmers. The farmers adopted some measures such as fish mortality disposal and disinfection of aquaculture gear (e.g., nets).
2. The activity increased farmer knowledge of vaccine usage for fish disease control. Future work should focus on formulating user-friendly vaccine delivery methods.

Tangible Impacts

This activity increased awareness of the positive impact of biosecurity and appropriate husbandry on fish survival and growth. In addition, the vaccine produced by the activity team was shown to be effective at reducing mortality, demonstrating to farms the benefit of locally produced vaccines in disease prevention.

Objective 3: Improve Human Outcomes from the Aquaculture and Fisheries Sectors

Quick Start Activity 3.1: SecureFish: Improved Nutrition Among Vulnerable Populations in Kenya Through Increased Access to and Consumption of Sustainable Fish Foods (SecureFish)

Location: Kenya

US PI: Lora Iannotti, PhD, Washington University in St. Louis
US Co-PI: Austin Humphries, PhD, University of Rhode Island
US Co-PI: Terezie Mosby, EdD, Mississippi State University
HC PI: Andrew Wamukota, PhD, Pwani University

HC Co-PI: Elizabeth Kamau-Mbuthia, PhD, Egerton University

Objectives:

1. Identify nutritious coastal marine fish for food that maintain ecosystem functioning.
2. Assess the acceptability and feasibility of these fish as foods for nourishing vulnerable populations of pregnant and lactating women and young children.
3. Determine market conditions for ensuring availability, affordability, and safety of these coastal marine fish as food.

Executive Summary: In Kenya, 47% of the population live below the poverty line, and 26% of children under 5 years old have stunted growth, an indication of persistent and serious nutrition insecurity. Fisheries are chronically overexploited, and this can be seen in the four-fold decrease in catch for coastal fisheries since the 1980s. Nationally representative data indicate low dietary diversity in vulnerable groups, and only a small fraction of young children (20.9%) reported to have consumed any fish, meat, or poultry. Some of the most vulnerable people to malnutrition and nutrient deficiencies are those along Kenyan coastlines and include infants and young children, pregnant and lactating women, and school-aged children living in poor households.

Small-scale fishing has large-scale implications because it can ensure well-being by providing nutrient-rich foods in the household diet. The SecureFish activity generated evidence that will inform other research initiatives to improve human welfare and nutrition using eco-sensitive approaches to fish foods. The overall goal of this activity was to improve nutrition among vulnerable populations in Kenya through increased access and consumption of sustainable fish foods.

Data collection occurred along the coast of Kenya in four communities: Vipingo, Uyombo, Shimoni, and Tiwi. The nutrition sample consisted of fishing (n = 100) and nonfishing households (n = 100) with children less than 5 years of age. Mixed methods were applied, including quantitative surveys with primary caregivers and children 5 years of age or younger. The team also conducted qualitative research via key informant interviews with caregivers of young children and individuals participating in the marine fish value chain. The findings from this study can be used to develop interventions that are aimed at improving human welfare and nutrition using eco-sensitive approaches to fish foods.

<u>Results</u>

The team collected anthropometric measures on young children with an average age of approximately 2 years, though the children ranged in age from 6 months to 5 years old. Overall, stunting affected one in five children across the sample (20.6%). A higher proportion of children were stunted in fishing households (22.0%) compared to nonfishing households (18.4%). The team found 43% of children were reported to consume fish in the previous 24 hours with significant differences by fishing (52%) vs. nonfishing (34%) household ($p = 0.01$). The communities in Kilifi County showed higher stunting rates than those in Kwale county. Underweight prevalence was also higher in fishing households (16.0%) compared to nonfishing (10.1%) as was wasting, though overall prevalence (2.5%) was low.

The analysis of diets of the children in the sample showed a poor-quality diet with low dietary diversity. The low dietary diversity translated to poor nutrient intake of all nutrients analyzed, where no child was able to meet 100% of their daily nutrient requirements for any nutrient in the previous 24 hours. Maize was the primary source for energy and some key nutrients, implying very poor diets for the access of nutrients required for growth and development of the children. It is also clear that fish consumption by the children was very low with most children just being

given fish soup without the fish flesh. This provides an opportunity for improving child protein intake amongst other nutrients by encouraging increased consumption of fish. These results show a great need for nutrition education for improved child feeding in these communities.

The distribution and access to fish (for local households) from the coastal small-scale fishery was mediated by season and location. The Northeast monsoon (*kaskazi*) season, where the wind blows from the north, is calmer, and catches for all fishes and octopus were higher than in the Southeast (*kusi*) monsoon season during which the sea is rough. This difference was most pronounced for octopus that had lower prices during kaskazi and higher prices during kusi. The differences in prices during the two seasons were attributed to supply and demand dynamics. The prices of fish were generally lower in the south coast than the north coast, and the revenue was thus accrued to actors. This could be attributed to the fact that traders in the south coast travelled long distances (>5 km on average) to the landing sites and that their recurrent costs (due to long travel distances) likely played a role in keeping fish prices low. There was more evidence of fish preservation in the value chain at the north coast sites due to high prevalence of different capacities of fish storage infrastructure.

The value chains for each fishery (i.e., octopus, pono, tafi, changu) differed:

- Octopus flowed through women fryers to consumers and supported the most diverse assemblage of actors.
- Most changu (emperor) flowed through women fryers either directly or via large-scale traders, an indication of the fish's importance in contributing to local consumption needs.
- Pono's (parrotfish's) value chains differed from the north to south coast: in the north, the flow was from fishers to women fryers to consumers, and in the south, the flow was through large scale traders.
- Most of the tafi (rabbitfish) flowed to consumers from women fryers through large-scale traders and supported a diverse set of actors in the value chain.

In most of the value chains, large-scale traders were predominant actors, controlling comparatively large volumes. Fisheries landings indicated that changu were being overfished severely because catches consisted of primarily juveniles, while tafi were the most sustainable and most resilient (to overfishing) catch of reef fish. Pono catches consisted of immature individuals as well. Pono serves an important role in the coral reef ecosystem, functioning as herbivores; therefore, its population is vital for environmental health.

Conclusions

The findings showed small fisher households along the Kenyan coast, despite livelihood engagement in fisheries, lacked dietary diversity and were more malnourished in terms of stunted growth and underweight status compared to nonfishing households. Cost was a major impediment to use of fish in children's diets, which might be mitigated through increased production. Caregivers expressed receptivity to nutrition education, opening the opportunity for improving feeding behaviors and fish in children's diets. The fisheries value chain analysis revealed that octopus play a critical role in the livelihood and wellbeing of fishers and coastal communities, and that the three major types of finfish (tafi, pono, changu) all support diverse and complementary sets of actors. Tafi emerged as the most sustainable fish to harvest, as its catches indicate mostly sustainable harvesting, while juvenile changu are being caught and pono are incredibly important for healthy coral reefs and thus are vital to keep in the water to maintain ecosystem functioning. SecureFish's formative research was applied to design an intervention that integrates sustainable fisheries production with social marketing for nutrition security among small fisher households on the North Coast of Kenya, which resulted in the

Samaki Salama activity.

Lessons Learned

The activity demonstrated that while fishing is an important livelihood, fish does not significantly contribute to the nutrient intake of children. Hence, opportunity was identified to develop nutrition education and social marketing messages on the importance of healthy diverse diets with special emphasis on fish nutrition for the growth and development of children. The team found that children in fishing households were more malnourished with higher rates of stunting, underweight, and wasting, allowing for greater intervention response by increasing fish in complementary feeding diets and diversifying diets. The activity identified women fryers (*Mama Karanga*) as vital actors in the fisheries value chain. This is the only place that women are engaged in the fishery, and thus greater attention should be placed on gender equity and opportunity, including involving Mama Karangas in the decision-making related to fisheries management and value chain improvements. The team also identified octopus as being important for local wellbeing and livelihood, warranting further research into its nutritional benefits. Among the different fish species, tafi were the most sustainable option for fisheries that do not negatively impact ecosystem functioning, so gear modifications and interventions should be aimed at reducing pono and changu catches while increasing the catches of adult tafi. This could be done through increases in trap fishing (which was also the most sustainable gear type) and installing escape gaps in these traps to allow juveniles to escape.

Quick Start Activity 3.2: Fish4Zambia: Assessing Facilitators and Barriers to Aquaculture and Fish Consumption in Zambia (Fish4Zambia)

Location: Zambia

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U.S. Co-PI: Mary Read-Wahidi, PhD, Mississippi State University
U.S. Co-PI: Elin Torell, PhD, University of Rhode Island
HC PI: Lauren Pincus, PhD, WorldFish
HC Co-PI: Pamela Marinda, PhD, University of Zambia

Objectives: Fish4Zambia aimed to increase the quality/quantity of fish benefitting nutrition and food security in Zambia, especially for women and children in the first critical 1,000 days of life. The activity had the following objectives:

1. Assess the current state of small fish (e.g., kapenta and chisense) capturing, processing, and trading activities from point of catch through processing to local and distant markets for sale in both rural and urban areas.
2. Identify the social and gender barriers to entry and/or participation in these value chain activities for the different actors, particularly women and youth.
3. Assess how small, captured fish are accessed by different consumer groups and consumed within households, especially in households in rural and urban areas distant from their source of production.
4. Explore the potential of upgrading the small-fish value chain via improving processing, storing, and trading methods to reduce postharvest losses and improve food safety.
5. Explore the use of small, dried fish for further processing into fish powder and incorporating into locally appropriate foods for enhanced nutrition of women and children in the first 1,000 days of life.

Executive Summary: This activity team implemented the Women's Empowerment in Fisheries Index (WEFI) and conducted separate focus group discussions (FGDs) among men, women,

and youth engaged in fishery sector activities in Zambia's Lake Bangweulu region. Fish4Zambia also conducted key informant interviews with Ministry of Health and Ministry of Fisheries and Livestock senior personnel serving the Lake Bangweulu region.

Activity Goal

Fish4Zambia's goal was to better understand how gender equity and other socioeconomic factors within the fishery sector impact women, men, and youth and to help transition rural women and their children, families, and communities toward better food security, nutrition, and economic development through sustainable production of fish. To achieve this goal, the team modified and implemented the WEFI, which had previously been adapted by WorldFish from the Women's Empowerment in Agriculture Index, and developed and implemented novel sets of FGD guides and key informant interview guides.

Data Collection Methods

Fish4Zambia's fieldwork was conducted at Lake Bangweulu in the Samfya District of Luapula Province. Using the WEFI, the team collected quantitative data from 397 men, women, and youth who engaged in fish value chain activities at Lake Bangweulu. Sixteen FGDs were conducted among men and women ages 30+ years engaged in fish value-chain activities, and five FGDs were conducted among youth ages 18–29 years who also engaged in fish value-chain activities. Two key informant interviews were conducted with Ministry of Health senior personnel serving the region, and one key informant interview was conducted with Ministry of Fisheries and Livestock senior personnel serving the region.

Village selection, community mobilization, enumerator recruitment, and data collection were conducted in partnership with the DoF of the Ministry of Fisheries and Livestock. All Fish4Zambia enumerators were able to speak the local dialect(s) used in the fishing villages and fishing camps in which the survey was implemented, and they completed the full-day WEFI Enumerator Training Workshop, which included training on the protection of human subjects. The analyses focused on WEFI gender-disaggregated results to explore two primary research questions:

1. How do men's and women's responses compare across the Household Hunger Scale, which measures household-level hunger in the past 4 weeks for three "hunger events"?
2. How do responses among men and women compare across WEFI modules, including the sample's demographics, decision-making on income-generating activities across the fish value chain, ownership of assets, community leadership, and gender norms?

Results: Demographics

The sample (N = 397) was nearly equally divided among men (48.6%) and women (51.4%), of whom a majority were adults ages 30–72 years (65.5%) versus youth ages 18–29 years (34.5%). All respondents were from Luapula Province, and a majority were from Samfya District (83.9%) and identified their ethnicity as Bemba (80.6%). A majority (88.7%) were married and lived in male-headed households (81.1%) as compared to households headed by husband-wife dyads with mutual decision-making influence (14.4%). A significant difference in education existed among men and women, with women (23%) more likely than men (9.3%) to report non-completion of any years of school. Most men (86.5%) reported their occupation as fishing, versus 31.4% of women. In contrast, 46.6% of women reported their occupation as selling fish versus 8.3% of men. No men reported their occupation as fish processing, as compared to 7.8% of women. A significant difference in occupation existed among men and women, with men (86.5%) more likely to report fishing and women (46.6%) more likely to report selling fish as their occupation.

Results: Research Question 1

The Household Hunger Scale gender-disaggregated results indicated significant differences in reported household-level hunger among women as compared to men for each of the three hunger events:

- Hunger Event 1: Women (67.1%) were significantly more likely than men (54.5%) to report that, in the past 4 weeks, there was no food to eat in their household due to lack of resources to acquire food.
- Hunger Event 2: Women (64.7%) were significantly more likely than men (46.1%) to report that, in the past 4 weeks, they or another household member had gone to sleep at night hungry because there was not enough food.
- Hunger Event 3: Women (49.1%) were significantly more likely than men (31.1%) to report that, in the past 4 weeks, they or another household member had gone a whole day and night without eating anything because there was not enough food.

Results: Research Question 2

WEFI gender-disaggregated results indicated significant differences among men and women across a range of income-generating activities, asset ownership, and decision-making power. For example,

- Men were significantly more likely to have engaged in fishing and selling fish in the past 12 months.
- Men were significantly more likely to report sole ownership of 1) locally produced fishing equipment; 2) synthetic nets, line, hooks, and other externally produced fishing equipment; 3) fish-processing equipment; 4) canoes; and 5) basic mobile phones. In contrast, women were significantly more likely to report sole ownership of fish-storage equipment such as baskets.
- Men were significantly more likely to report that they had a large amount of decision-making input into the key value chain activities of fishing, processing fish, transporting fish, and selling fish.
- Men were significantly more likely to have met with a fisheries extension officer in the past 12 months.
- Women were significantly more likely to report they were not at all comfortable speaking in public 1) to help decide on projects and issues affecting their fishing camp or village, 2) on decisions related to governing the fishery, and 3) to protest the use of illegal or unsustainable fishing practices.
- Most women (67.2%) and men (74.6%) agreed with the statement, “Women should not be involved in fishing fulltime; this is a man's responsibility.”
- In contrast, most women (56.9%) and men (51.3%) disagreed that “Women should not own canoes, fishing nets, and other means to fish,” and a majority of women (76%) and men (68.3%) disagreed that “Men should primarily be the ones who control the earnings obtained from the sale of fish, not women.”

Discussion of Key Results

While women were significantly more likely than men to have reported that they or another household member had experienced each of the three hunger events from the Household Hunger Scale, the percentage of both men and women who reported household-level hunger for

each hunger event was noteworthy. The results suggest a need to explore what factors make women in this sample more likely to report food insecurity as compared to men. Is it that local gender norms dictate that men are served first in respondents' households and, as a result, women get less food or eat nothing when there is a food shortage? Or are women more aware of food shortages within their households due to their traditional role as food-preparers? This gender-disaggregated data highlights 1) the importance of taking gender into account to more accurately reflect how food insecurity can impact different household members, and 2) the need for more data on how variations in gender norms impact coping strategies to food shortages among fishing community members. Likewise, the significant disparities in education level among men and women in this sample is cause for concern given that less access to education, literacy, and numeracy are known to contribute to undermining women's economic development and access to opportunities across the fish value chain. Increasing women's participation in higher income- generating activities along the fish value chain (e.g., fishing) as well as their decision-making input may expand women's opportunities to improve their economic resilience.

Lessons Learned

Men and women have bifurcated roles within the fish value chain in the Lake Bangweulu region. Men and women handle different fish, with women processing and selling/trading small and low-value fish and men prioritizing larger and higher value fish that is primarily sold fresh. Although both men and women in fishing communities benefit economically from the fisheries value chain, women are largely constrained to activities that are less profitable, and men participate in the most beneficial nodes of the fish value chain. The study found that it is essential to empower youth by engaging them in sustainable fisheries management and providing access to credit. This will enable male and female youth to participate fully in the fishery sector. Opportunities to improve nutrition via fish consumption are not optimally harnessed among Lake Bangweulu fishing communities because of existing social norms and low knowledge on the nutritional importance of fish in diets. Nutrition education is critical for mothers to acquire knowledge on the importance of fish and skills on how to better integrate fish in their children's' diet.

Activity 3.1: Harnessing Machine Learning to Estimate Aquaculture Production and Value Chain Performance in Bangladesh (Harnessing Machine Learning)

Location: Bangladesh

Lead and U.S. PI: Ben Belton, PhD, Michigan State University
U.S. Co-PI: Amirpouyan Nejadhashemi, PhD, Michigan State University
HC PI: Mohammad Mahfujul Haque, PhD, Bangladesh Agricultural University
HC Co-PI: Khondker Murshed-e-Jahan, PhD, WorldFish

Objectives:

1. Identify emerging technologies and innovative practices in aquaculture value chains and pilot digital extension approaches that accelerate their adoption to enhance productivity, resilience, and human nutrition, while reducing the transaction costs and time associated with traditional forms of technical research and extension.
2. Use machine learning to automate extraction of data on ponds from satellite images and integrate with georeferenced survey data to accurately estimate fish production, employment, and economic value; improve the accuracy of official statistics; and enhance capacity to target investments and regulation.
3. Build organizational and individual capacity in Bangladesh for conducting state-of-the-art research on socioeconomic and spatial dimensions of aquaculture development and contribute to societal capacity to create a more enabling environment for fostering

sustainable aquaculture development.

Executive Summary: Lack of rigorous data collection means that “conventional wisdom” about aquaculture often lags far behind conditions on the ground and makes aquaculture production statistics unreliable. Inadequate information makes it difficult to plan and manage aquaculture development, or design investments, policies, and interventions effectively. Moreover, new technologies and practices developed by innovative farmers and supply-chain actors often go unrecognized and may diffuse more gradually than they would if promoted actively by formal extension agents. Digital technologies are undergoing a revolution. Artificial intelligence (machine learning), remote sensing, smartphones, mobile internet, social media, and opensource data collection and video production software open an array of new possibilities for cheaply collecting, analyzing, and communicating information in new forms to multiple audiences. Drawing together these strands, this activity combined survey-based research techniques with remote sensing, machine learning, and video production to generate knowledge products disseminated via digital media to reach and serve the diverse information needs of fish farmers, enterprises, researchers, and government. The activity had three components.

Innovative Digital Extension Approaches

Component 1 identified emerging technologies and innovative practices in aquaculture value chains and piloted digital extension approaches to accelerate their adoption, while reducing transaction costs and time associated with traditional forms of technical research and extension. To do so, the team followed the “stacked survey method” developed by Michigan State University to survey a total sample of 1,195 value-chain actors in seven districts in the Feed the Future Zone of Influence in southern Bangladesh, comprised of 66 hatcheries, 79 feed suppliers, 721 farmers, 229 fish traders, and 100 fish retailers. Around 75% of surveyed actors were interviewed by Michigan State University in 2013. Additional in-depth interviews were used to gather detailed information on innovative practices and produce short videos featuring individuals talking and demonstrating their innovative behavior in their own words to provide easily relatable content to be disseminated widely through social media platforms.

Use Machine Learning to Analyze Fishponds

Component 2 focused on automating extraction of data on ponds from satellite images and integrating it with georeferenced survey data to accurately estimate fish production, economic value, and employment (disaggregated by gender and age) to improve the accuracy of official statistics and enhance capacity to effectively target investments and regulation. The team utilized machine learning techniques to extract and analyze data on fishponds from satellite images. In combination with data collected under Component 1, this analysis facilitated development of an interactive online data visualization tool used to estimate aquaculture’s multidimensional contributions to the economy and nutrition, focusing on production, economic value added, and employment, all differentiated by gender. The publicly available web-based tool was designed based on stakeholder consultations to facilitate user interaction with and visualization of the data generated.

Build Research and Analytical Capacity

Component 3 worked to build organizational and individual capacity in Bangladesh for conducting rigorous research on the socioeconomic and spatial dimensions of aquaculture and contribute to the development of an enabling environment for fostering sustainable aquaculture growth. Capacity building activities included 1) stakeholder consultations on features potential users wished to see incorporated into the interactive geographic information system interface; 2) data collection and analytics training to build host-country researcher capacity for quantitative survey data analysis, analytical thinking, and written and oral academic presentation skills; 3)

dissemination of Bangla-language extension videos via social media; 4) an online six-part remote-sensing capacity-building course for geographic information system users; and 5) three closing workshops to promote new and emerging technologies to private-sector actors and extension agents at the national level and in the surveyed zones.

Conclusions and Recommendations

The activity was highly effective in delivering multiple policy and capacity-building-oriented research outputs under difficult circumstances during the COVID-19 pandemic. The activity introduced multiple innovative methodologies and approaches that can be adapted for use in other contexts and locations by future projects, and it generated significant interest and proactive support from the DoF. Future efforts could work to scale out these approaches to other countries and mainstream them within Bangladesh. Recommendations include the following:

- Integrate remote sensing and machine learning techniques with ground-truthing and statistically representative surveys to improve the quality and scope of aquaculture production statistics.
- Expand the application of the analytical methods developed by the activity to the national scale in Bangladesh in partnership with the DoF, Bureau of Statistics, and internationally with other partners.
- Extension videos featuring innovative farmers and other value-chain actors can be simple and cost effective to produce but require professional support to maximize dissemination through social media to reach large numbers of end users.
- Virtual capacity-building activities, such as online workshops, can reach much larger numbers of participants at lower cost than in-person workshops.

Lessons Learned

Difficulties recruiting qualified data analysts slowed down production of research outputs, and some data analysis activities were initiated later than scheduled. However, the team addressed this by bringing in a Michigan State University graduate research assistant (without Fish Innovation Lab funding) to provide analytical support. The team in Bangladesh learned about the technical aspects of video production. Further work is needed to identify ways to optimize dissemination of the content generated by the activity through social media.

The final closing workshop received strong buy-in from the DoF, which hosted the event as an official program at its headquarters in Dhaka, ensuring a high level of attendance by key DoF staff. The DoF has endorsed the machine learning approach to estimating aquaculture production indicators and has expressed interest in incorporating it into DoF practices.

Useable Outcomes

1. A publicly accessible interactive online data visualization tool combining information from remotely sensed images and surveys to estimate aquaculture's multi-dimensional contributions to the economy of Southwest Bangladesh, focusing on production, economic value-added, and employment – all differentiated by gender and value chain segment
2. Thirteen short extension videos featuring farmers talking about innovative practices and adaptations in their own words
3. A dedicated project 'Aquaculture TV' Facebook page and YouTube channel
4. One online remote sensing and machine learning training course with six instructional

videos

5. An online interactive decision-making tool for visualizing survey results, hosted on the Michigan State University server

Tangible Impacts

1. The activity developed a novel methodology for estimating accurate statistics on aquaculture pond area, aquaculture production, aquaculture contributions to employment on- and off-farm, by gender, and contributions to regional economies to generate estimates of a much wider range of performance indicators than are conventionally collected to support planning and investment decisions. This method can be adapted to work in any geography globally.
2. The activity developed a methodology for estimating the nutrient productivity of aquaculture (expressed as numbers of adults able to meet their full dietary requirements for a range of nutrients from 1 hectare of land under aquaculture production) and identifying combinations of crops that maximize economic productivity (expressed as gross margin per hectare) and nutrient productivity. This method has potentially much wider applications to all types of crop farming systems.
3. The activity tested the potential for using short, low-cost extension videos to disseminate knowledge and information on aquaculture technologies via social media to reach large audiences and accelerate the rate of aquaculture technology transformation. Further work is needed to optimize diffusion of these videos to target audiences through the application of social media marketing techniques.

Activity 3.2: Nourishing Nations: Improving the Quality and Safety of Processed Fish Products in Nigeria (Nourishing Nations)

Location: Nigeria

Lead PI: Monica Pasqualino, PhD, WorldFish
U.S. PI: Terezie Tolar-Peterson, EdD, MS, RDN, LDN, FAND, California State University, San Bernardino
HC PI: Henrietta Ene-Obong, PhD, University of Calabar, Cross River State

Objectives:

1. Develop cost-per-nutrient guides by analyzing the nutrient and contaminant profile of select processed fish products and their respective prices in comparison to other animal source foods available in Delta State, Nigeria.
2. Build capacity among women and youth fish processors in Delta State to produce high quality, safe, and nutritious processed fish products for local consumption.
3. Educate women and youth fish processors in Delta State about the benefit of fish in the human diet and develop a low-literacy tool to help them better market their product.

Executive Summary: As an affordable and accessible animal source food in Africa, fish is important for many poor and marginalized women, men, and youth. However, fish processing methods in Nigeria remain limited to traditional salting, sun drying, and smoking methods. These methods expose fish to pests, insects, microorganisms, sand, and dirt. Smoked fish face an additional health hazard of accumulation of polycyclic aromatic hydrocarbons due to high wood burning temperatures. Although processing fish is an important method of reducing postharvest loss, traditional methods can lead to a multitude of food safety issues that put consumers at risk. Additionally, heat, sunlight exposure, and fermentation processes alter the nutrient content of fish.

Understanding how traditional processing methods impact the nutritional content of fish can help policymakers in prioritizing investments and interventions to ensure the safety of these important food products.

Capacity Building Among Fish Processors

The activity strengthened capacity among fish processors in Delta State through a training program administered across two workshops. During the first workshop, 122 fish processors were trained on the benefits of fish for human health and how to educate others about these benefits using simple low-literacy tools, which included wristbands, aprons, and fans with messages about fish for health and nutrition. Sessions were also held on hygienic food handling. The second training workshop provided 75 fish processors with information and hands-on practical experience to improve the quality and safety of fish products as well as strengthening their business and entrepreneurial skills to expand their businesses and financial access. Sessions during this workshop included topics on entrepreneurship, financial access, business plan development, formation and operation of cooperative societies, fish handling and packaging techniques, traditional and modern fish smoking and drying techniques, and value addition. An evaluation of the second workshop revealed that almost all participants (97%) rated the training highly and were willing to utilize the knowledge and skills gained. Overall, the training program enabled fish processors to grow their businesses, increase their market share, and diversify their product lines.

Engaging Women and Youth in the Fish Processing Sector

Women represented the majority of activity participants (about 70%), creating opportunities for female empowerment through collective action and business strengthening. By participating in the training program, women and youth gained knowledge on the nutritional value of fish and how to develop products that could satisfy the nutritional needs of pregnant and lactating women, infants, and young children. This knowledge also gave them the means to develop fish products of higher quality and value, thereby strengthening market demand for their products. The training sessions on improved fish handling and processing and entrepreneurship further strengthened their skills as empowered actors in the fish processing sector. Additionally, platforms were developed to link fish processing cooperatives to strengthen collaboration and foster the exchange of knowledge, information, and skills.

Fish for Human Nutrition

In addition to improving knowledge about the nutritional value of fish and strengthening processors' skills to create high quality fish products, the activity conducted research to inform national nutrition policies and guidelines. Data were collected on the nutrient and contaminant profiles of select processed fish products as well as their respective prices to create cost-per-nutrient guides, which enable comparison between fish products and other animal source foods. The team completed fish sample collection and analysis as well as four market surveys to capture seasonal fluctuations in price. The guides allow for an informed examination of the food environment in Nigeria and can support government stakeholders as they design nutrition-sensitive programs and policies. The information can also be used to update the Nigerian Food Composition Table and national Food-Based Dietary Guidelines, which are often used in the design of nutrition education content and messaging. Data on the contaminants present in the fish products can also be used by policymakers to identify and mitigate food safety issues in this sector.

Recommendations

The activity improved food and nutrition security by increasing knowledge and awareness of the importance of fish in the diet and food safety issues in the fish sector, strengthening women's social and economic empowerment through business training and improved product development, increasing production of nutritious and safe fish products, and improving consumer access to high

quality and safe processed fish products. To expand upon the accomplishments of the activity, the following recommendations are suggested:

1. Stakeholders should be engaged to capitalize on use of the training and educational materials developed through the activity to continue creating opportunities for fish processors to strengthen their knowledge and skills. Information dissemination on improved fish processing, value addition, and new fish product development should continue through workshops, lectures, seminars, and sensitization programs on television, radio, and social media.
2. Although the fish processing business provides employment opportunities and income to many in Delta State, particularly women, the absence of improved infrastructure, facilities, and equipment for processing may hamper efforts toward improving the nutrition and safety of processed fish products. Adequate funding of the sector is critical to promote the adoption of safe and quality improved practices along the fish processing value chain.
3. Additional longitudinal studies should be conducted to evaluate the food security determinants of dietary diversity among women of reproductive age and children, with emphasis placed on raising awareness on the importance of dietary diversification.
4. The research data on the nutrient and contaminant profiles of fish should be utilized to inform national guidelines, programs, and policies focused on nutrition, food security, and food safety.

Lessons Learned

Due to personnel turnover at UoC, the institutional DUNS number was not renewed timely, creating significant challenges to completing implementation. The team held discussions with the ME to find solutions and decided to pursue an agreement modification to allow WorldFish to receive and distribute the funds to complete the training program in Delta State. The two trainings originally planned (one on fish processing techniques, another on business skills development) were combined into one longer workshop covering all topics while maintaining the participant number. This situation raised awareness among researchers about the importance of the research administration component of implementing research-for-development grants. Team members appreciated the Fish Innovation Lab ME efforts to develop the capacity of PIs and co-PIs through training meetings and workshops and the opportunity to interact with other researchers in aquaculture.

Useable Outcomes

A low-literacy seven-module flipbook on nutrition and safe fish handling and processing for fish processors in Nigeria was developed and successfully validated as suitable and culturally appropriate for the target population. The flipbook has the potential to contribute to the improvement of knowledge about nutrition, healthy eating, dietary diversity, food security, and animal source food as a nutrient source to mitigate malnutrition among children, young female adolescents, and women in low- to middle-income countries. The newly developed and validated flipbook will be available to the public in a printable and downloadable form for teaching low-literacy fish processors nutrition, safe fish handling, and processing.

The training materials developed for the second workshop focused on fish processing skills and entrepreneurship were developed in collaboration between project team members and workshop facilitators, including government and non-government stakeholders. These tools can be used for future trainings to build capacity among fish processors in Nigeria, and as a foundation for subsequent training materials.

The nutrition and food safety training improved the dietary diversity of women fish processors of

reproductive age. In addition, there was an increase in the consumption of animal source proteins including eggs, green leafy vegetables, dairy products, nuts, and legumes. Increased intake of animal source foods contributed to the increase in dietary diversity score.

The cost-per-nutrient guide developed will be a useful educational tool for making informed food choices for different target groups. The training manuals for the two training workshops and one peer-reviewed publication will be useful resource materials for future training and researchers.

Tangible Impacts

One of the long-term impacts of this activity is the improved knowledge of the benefits of fish in the human diet and in infant and young child feeding. This will go a long way in improving household food security, nutrient intakes, and, consequently, improved nutrition and health of the target populations. Optimum nutritional status has a multiplier effect; it has significant positive effects not just on physical and cognitive development but also on national development. There was also a significant improvement in the safe handling and processing of fish by processors. The long-term effect of this is the availability of good quality processed fish products in Delta State, which will benefit the general population.

Through its training program, the activity has significantly impacted fish processors, fish producers, and other fish value-chain actors. Most participants started expanding their businesses as a result of the activity. For example, a male fish producer who lived in a neighboring town close to the capital city complained of low patronage and low pricing of his catfish in his locality. As a result of the training, he engaged young adults who will start a fish barbecue stand in his area. This will provide an outlet for his fish, provide him more money for the fish produced, expand his business, and increase his earnings.

The training also helped existing fish processors increase their knowledge, particularly on fish packaging techniques, access to funds, developing business plans, and cooperative societies. If applied, this information and skills will enhance and sustain their businesses.

Another tangible and long-term benefit of this activity is the data generated, particularly on nutrient composition of commonly consumed processed fish products. This data will make valuable contributions to the Nigerian food database and other international databases (e.g., ongoing updates of the FAO Fish database).

Activity 3.3: FishFirst! Zambia: Research for Development and Scaling Staple Fish Products for Enhanced Nutrition in the First 1,000 Days of Life (FishFirst! Zambia)

Location: Zambia

Lead and U.S. PI: Kathleen Ragsdale, PhD, Mississippi State University
U.S. Co-PI: Mary Read-Wahidi, PhD, Mississippi State University
HC PI: Netsayi Noris Mudege, PhD, WorldFish

Objectives: FishFirst! Zambia aimed to increase the quality/quantity of fish benefitting nutrition and food security in Zambia, especially for women of reproductive age (ages 15-49 years) and children in the first 1,000 days of life (under 2 years). The objectives of FishFirst! Zambia were to

1. Assess the current state of small pelagic fish harvesting, processing, and trading activities from point of catch through processing to local and distant markets for sale in rural and urban areas.
2. Identify social and gender barriers to entry and/or participation in these value chain activities for different actors, particularly women and youth.
3. Assess how small pelagic fish are accessed by different consumer groups and

household consumption.

4. Explore potential of upgrading the small pelagic fish value chain via improving processing, storage, and trading methods to reduce postharvest losses and improve food safety.
5. Develop and test nutrient-enhanced Complementary Food for Africa + dried fish powder (ComFA+Fish) products/recipes for enhanced nutrition particularly benefiting women of reproductive age and children under two years in vulnerable households.
6. Explore options to scale the production and dissemination of ComFA+Fish products/recipes with private- and public-sector actors, particularly women and youth entrepreneurs.

Executive Summary: Despite great progress in the last two decades, undernutrition among infants and young children (IYC) in Zambia is categorized as serious, with 34.6% of children under five years being stunted and having daily intakes of energy, calcium, iron, and vitamins below recommended levels. During the complementary feeding stage, malnutrition risks increase as vulnerable IYC begin consuming diets that rely heavily on cereal-based staples (e.g., maize) that lack essential protein, fats, and micronutrients. Although multiple micronutrient powders—standardized prepackaged vitamin/mineral sachets distributed by international donors—have helped reduce global rates of stunting among vulnerable IYC, they have had less impact on protein malnutrition.

FishFirst! Zambia's goal was to determine feasibility of harnessing the power of nutrient-dense pelagic small fish—locally available animal source foods that provide protein, fat, essential micronutrients, and vitamins A, C, B12, E, and D—to help fill protein and micronutrient gaps among food-insecure IYC and families. The research team developed a novel fish-based protein/micronutrient blend, ComFA+Fish. The activity's work was concentrated at Lake Kariba, Zambia's primary source of pelagic small fish known as Kapenta (*Limnothrissa miodon* and *Stolothrissa tanganicae*), and this fish was used as the principal ingredient of the ComFA+Fish protein/micronutrient blend evaluated during FishFirst! Zambia.

FishFirst! Zambia Phase I: Women's Empowerment in Fisheries Index (WEFI)

In 2021, the research team administered six survey instruments to a random sample of 485 Lake Kariba fishers, processors, and traders. These included questions to assess women's economic and decision-making empowerment, individual- and household-level hunger, postharvest fish loss across the value chain, dietary diversity among women of reproductive age, and dietary diversity and anthropometric data among 6–23-month-olds.

FishFirst! Zambia Phase II: Assessing Sensory Acceptability of ComFA+Fish

In 2022, the team conducted fish-focused nutrition trainings, cooking demonstrations, and sensory panels. For Sensory Panel I, caregivers evaluated seven attributes—aroma, appearance, texture, taste, sweetness, convenience, and overall acceptability—of four ComFA+Fish dishes. These dishes included: 1) ComFA+Fish Complementary Maize Porridge; 2) ComFA+Fish Chibwabwa Fisashi (a pumpkin leaf-based savory dish); 3) ComFA+Fish Kapenta Chutney (a savory dish of whole pelagic small fish); and 4) ComFA+Fish Bean-Vegetable Soup. For Sensory Panel II, caregivers evaluated acceptability of ComFA+Fish Complementary Maize Porridge among their IYC. For both panels, a majority of caregivers evaluated the dishes as highly acceptable. Most importantly, ComFA+Fish Complementary Maize Porridge was evaluated as highly suitable as a food not only for IYC but for the entire household, which suggests ComFA+Fish can help fill protein and micronutrient gaps among food insecure IYC and families. The nutrient analysis of Kapenta dried fish powder and the

ComFA+Fish Sensory Panel I-II results are available at https://tinyurl.com/n77x8kwj.

FishFirst! Zambia Phase III: Assessing Scalability of ComFA+Fish

In 2023, the team collaborated with Sylva Food Solutions—a multisectoral Zambian enterprise that mass produces, brands, markets, and exports prepackaged foods for African and European markets—to produce two ComFA+Fish instant porridges for evaluation during a learning event and workshop. Attendees included mothers, community health workers, entrepreneurs/business owners, and government officials (i.e., Ministry of Health, DoF, and other governmental personnel). They evaluated acceptability of plain and vanilla ComFA+Fish instant porridges during Sensory Panel III and participated in focus group discussions on nutrition priorities. They also participated in an exercise to assess scalability of ComFA+Fish instant porridges. The results of ComFA+Fish Sensory Panel III and the scaling readiness exercise were both positive. The workshop's guest of honor, Siavonga District Commissioner Geoffrey Jakopo, launched FishFirst! Zambia's ComFA+Fish Recipe Booklet, which included a version for English speakers and a version for Tonga speakers.

ComFA+Fish and Potential for Adoption at Scale

The results of this research support the conclusion that improving the diets of at-risk IYC and other vulnerable household members is achievable by incorporating pelagic small fish into their daily meals via a protein/micronutrient blend such as ComFA+Fish that has demonstrated high nutritional content, is locally accessible, and is congruent with meal preparation among caregivers in the target populations. The primary ingredient of ComFA+Fish is pelagic small fish, a locally available animal-source food that provides protein, fatty acids, and essential micronutrients and vitamins. The positive evaluations across all three sensory panels and the scaling readiness exercise provide evidence that ComFA+Fish is strategically well-placed to address protein and micronutrient gaps among vulnerable 6–23-month-olds and families across Zambia and sub-Saharan Africa. This is particularly important for low-resource households that lack dietary diversity and rely on high-phytate, maize-based diets, which increases vulnerability to nutrient deficiencies. Having determined the feasibility of harnessing the power of pelagic small fish to benefit nutrition and help fill protein and micronutrient gaps among vulnerable IYC and families, the team recommends the following next steps: 1) complete a shelf-life study of Kapenta dried fish powder; 2) adjust the ComFA+Fish recipes as needed to ensure recommended serving sizes meet recommended Dietary Reference Intake values without compromising flavor and acceptability; and 3) continue to forge collaborations with tiered in-country partners to scale ComFA+Fish instant porridges at national (e.g., school feeding programs), regional (entrepreneurs), and village levels across Zambia and sub-Saharan Africa.

Lessons Learned

Collecting data for the WEFI from husband/wife pairs was difficult because often one spouse was not home when enumerators arrived in the community. This was resolved because collecting data from husband/wife pairs is intrinsic to the WEFI structure and cannot be avoided.

Useable Outcomes

The FishFirst! Zambia team collaborated with Sylva Food Solutions to provide dried fish powder and other locally sourced key ingredients, which they then used to produce two ComFA+Fish instant porridges for Sensory Panel III. Participants included government officials, entrepreneurs, NGOs, Ministry of Health staff, DoF staff, community health workers, and mothers from Gwembe, Siavonga, and Sinazongwe Districts. Between 85–100% of respondents extremely liked or liked the aroma, appearance, texture, flavor, sweetness, convenience, and overall acceptability of the vanilla porridge. Responses were similarly positive for all attributes of the plain porridge with the exception of flavor, which 79% of respondents extremely liked or

liked (as compared to 91% for the vanilla porridge). The high convenience and overall acceptability scores suggested the potential for wide-scale adoption of these porridges in Zambia and across sub-Saharan Africa. Innovation to Impact, the joint initiative of USAID and the Feed the Future Innovation Lab for Soybean Value Chain Research, selected ComFA+Fish as an innovation/technology with scaling potential.

Tangible Impacts

FishFirst! Zambia served to ground-proof scalability of ComFA+Fish to address protein and micronutrient deficiencies for IYC and improve birth outcomes in Zambia and across sub-Saharan Africa. Having determined high acceptability of ComFA+Fish, the team is completing a shelf-life study of Kapenta dried fish powder and seeking funding to conduct a randomized controlled trial among Zambian infants 6–8 months old, followed by a trial for children over 24 months. Outcomes are expected to contribute to the growing body of evidence that consuming locally sourced dried fish powder and other aquatic animal-source foods are promising as ways to reduce stunting and improve other nutrition-sensitive health outcomes in Zambia and across sub-Saharan Africa.

Activity 3.4: Samaki Salama: Securing Small-Scale Fisheries in Kenya for Healthy Nutrition and Ecosystems (Samaki Salama)

Location: Kenya

Lead and U.S. PI: Lora Iannotti, PhD, Washington University in St. Louis
U.S. Co-PI: Austin Humphries, PhD, University of Rhode Island
HC PI: Andrew Wamukota, PhD, Pwani University
HC Co-PI: Elizabeth Kamau-Mbuthia, PhD, Egerton University

Objectives:

1. Determine the effects of a multi-tiered social marketing campaign to promote fish nutrition, dietary diversity, and food safety on child growth.
2. Measure the impact of fishing gear cooperatives on gear modification and diversification as well as catch dynamics and earnings.
3. Describe fish access, safety, and consumption in a representative inland county with a view towards potential future application of the Samaki Salama intervention package.

Executive Summary: The Samaki Salama activity aimed to promote sustainable fisheries practices and improve the nutritional status of young children. The intervention study was conducted in Kilifi County among small-fisher households with children less than 5 years of age. The objective was to test the effectiveness of a bundled intervention to address human health and malnutrition in small-scale fisher households and its interaction with nutrition security and fisheries sustainability.

The study was a longitudinal, cluster-design trial with three groups: 1) control, 2) social marketing for nutrition education, 3) social marketing for nutrition education and modified fishing traps for fisheries health. Data was collected from households in all three groups at two points, which were baseline (before the implementation of the intervention) and endline (at the close of the 1-year intervention period). Fishers were interviewed on their fishing practices, fish catch, revenue, and total fish catch they took home, while caregivers were interviewed concerning feeding and care of the young children aged 6–59 months, and child growth was measured.

<u>Key Findings</u>

Fishers using gated (experimental) traps caught larger fish that were worth more money than

those using non-gated (control) traps, and the most commonly caught species were rabbitfishes and parrotfishes. The fishers that participated in the study had yields that were 10% greater (kg) than those fishers in the control group using non-gated traps, and the catches were worth 13% more in price. Two fish species were particularly impacted by the gated traps: Blackspotted sweetlips (*Plectorhinchus gaterinus)* and Blackspot emperor (*Lethrinus harak)*. These fish were often captured as juveniles in the non-gated traps, but because of the modified trap design, the length of fish was greater, suggesting more adult fish caught instead. Fishers took fish home with them to feed their family more than half of the time; however, fishers who received gated traps and social marketing took home significantly more fish (12% of catch) than those who did not (7% of catch).

Stunted growth was highly prevalent in this sample affecting 20% of children at baseline and increasing to 27.9% by endline. Acute diarrhea also was extremely high in the three study groups at baseline: 24% compared to the national average of 14% in Kenya. The Samaki Salama intervention showed positive findings across multiple nutrition and health outcomes. Data showed that the Samaki Salama intervention significantly increased child growth in height, significantly increased child fish consumption, and improved child dietary diversity score (number of food groups consumed).

Accomplishments

The Samaki Salama activity supplied 100 fishers with 400 modified basket traps. This enabled the fishers to have the same or more catch compared with the old traps, and the fish were worth more money because of their increased size. Fishers also caught fewer juvenile fish with the modified basket traps; thus, decreasing their impact on fish stocks. Fishers who were also targeted with the social marketing element of the intervention were willing to use the modified traps to protect the marine ecosystem and take home more catch for child nutrition. In the intervention group that combined social marketing with modified traps, children consumed more fish and a greater variety of foods, likely leading to improved health outcomes in the long-term.

Changes in caregiver health behaviors were evident in the two groups receiving social marketing messaging from home visits, cooking demonstrations, fisher workshops, and community healthcare workers. These behaviors were linked to improved dietary, health, and hygiene practices ultimately leading to reduced illness in the young children.

Recommendations

- The Samaki Salama activity recommends that social marketing with nutrition-based education is needed to engage individual caregivers to persuade and show them how to make positive behavior changes.
- There is a need to support small-scale fishers with appropriate fishing gear that can preserve the ecosystem, such as the gated traps, and incorporate the same gear in national fisheries regulation requirements. Fishers should also be trained on how to use such gear and how to sustain the practices.
- Male caregivers/fathers should be involved in child feeding and care, as this increases the likelihood that the nutritional status of children will be improved and the behavior change sustained in the household.
- More efforts are needed to enhance nutrition knowledge about the benefits of fish among fishing households to increase their intake and consequently improve the nutritional status and health of young children.
- Collaborations between community partners such as community health volunteers and representatives from BMUs should be strengthened for intervention sustainability and

adoption of appropriate practices.

Lessons Learned

- Prior planning, surveillance, and mobilization were key to project introduction, uptake, and overall success. However, while planning is vital, research teams should be prepared to adapt if needed.
- Increased interest in the activity was accompanied by additional requests from communities and participants. Although the team was not able to meet all the participants' expectations, the activity successfully promoted sustainable fishing practices and improved the nutritional status of young children.
- Teamwork is critical for success. The activity was a success due to the combined efforts of various key players including the Ministry of Health, Ministry of Fisheries, and the participating communities.
- Involving the community beyond the individual study participants increased rates of acceptance and adoption.
- Social marketing played a key role in the uptake of the intervention's messages and recommended practices. Many caregivers reported that they would check the reminder posters for proper meal planning, and their children would also remind them of foods in the posters. Fishers reported that their children reminded them to carry fish home for consumption.

Useable Outcomes

- The modified basket traps enabled fishers to have more fish catch and consequently more income. Some fishers reported that they expanded their businesses, while others ventured into livestock rearing (one fisher purchased two goats and planned to add more).
- The modified basket traps had spillover effects to other fishers who opted to make their own modified traps. They also wanted to capture large, mature fish that brought in more income.
- Caregivers changed their feeding habits and adopted the appropriate approaches promoted through the activity. Similarly, caregivers and community health volunteers reported that the caregivers had improved their care-seeking behaviors as well as their hygiene and sanitation practices. They reported that the improved health, growth, appetite, and weight gain of their children motivated them to continue with practices learned through the activity.
- Caregivers taught other women in the community, and community health volunteers reported that they had to educate other caregivers from households while doing their monthly visits assigned by the hospitals. Many women expressed interest in the activity and wanted to benefit from the education, too.
- Both fisheries officials and health workers expressed appreciation for the Samaki Salama activity's efforts to implement activities/initiatives that they also pursue or are unable to explore due to lack of funds and resources.

Tangible Impacts

- There was increased revenue from the increased fish catch, so households were able to meet their basic needs, pay school fees, pay off loans, and expand businesses.

- Take-home fish increased, and households consumed more fish more regularly. The caregivers reported observing the benefits in the health of their children.
- Caregivers changed their childcare and feeding practices. This improved the health and nutritional status of the children and reduced the incidences of illness among the young children.

Activity 3.5: Population Ecology and Current Distribution Assessment of the Introduced Invasive Crayfish in the Kafue Floodplain and Lake Kariba, Zambia (Zambia Crayfish)

Location: Zambia

Lead and U.S. PI: Michael Rice, PhD, University of Rhode Island
HC PI: Eva Nambeye-Kaonga, MS, University of Zambia
HC Co-PI: Marjatta Eilittä, MS, PhD, Cultivating New Frontiers in Agriculture

Objectives: The general objective of this study was to investigate the biology, ecology, and population of the invasive crayfish in the Kafue floodplains and Lake Kariba. The specific objectives were

1. To assess the current biology, ecology, and environmental situation of the invasive crayfish through understanding the reproductive rates, spread, and distribution throughout the Kafue floodplains and Lake Kariba in Zambia.
2. To determine growth parameters and growth performances of crayfishes in the two water bodies.
3. To determine the prolific breeding and reproduction of crayfishes in both rainy and dry seasons.
4. To assess relative abundance of crayfishes in the two water bodies and from crayfish farming.
5. To determine the relative distribution and invasion of crayfishes in both water bodies, throughout the floodplain, and in connected waterways.

Executive Summary: Since the 1990s, the exotic Australian red claw crayfish (*Cherax quadricarinatus*) has been spreading in the Zambezi River basin in Zambia. This activity determined the population structure of crayfish in Lake Kariba and from the Kafue River Basin. The study was conducted to document the population dynamics, continued spread of redclaw crayfish in the Zambezi River basin of Zambia, and the socioeconomic impacts of crayfish on traditional fishing communities. The study consisted of crayfish sampling, an online poll, a fisher survey, and focus group discussions in fisher communities.

Crayfish Sampling and Online Poll

The team sampled crayfish and measured length monthly using fishers' catch at designated sites. They estimated crayfish population dynamics using standard fisheries methods. The data revealed that the crayfish populations in both areas were robust with multiple age classes present. Maximum size of crayfish was determined to be 215.25mm (total length) in both areas. The team determined presence or absence of crayfish at locations throughout Zambia by administering a poll to members of the staff of the Zambian DoF assigned to various districts around the country and others.

The crayfish appeared in seven previously unreported locations in the Zambezi River basin, including the Kabompo River in the Northwestern Province, the Chingola Reservoir in the Copperbelt Province, and in the Kwando sub-watershed of the Zambezi Basin in the Western

Province that borders with Angola, which has a seasonal aquatic connection to the critical Okavango Delta Wildlife Refuge in Botswana.

Fisher Survey

The team interviewed a total of 342 fishers to investigate their attitudes and perceptions toward the crayfish. One fisher reported seeing crayfish as early as 1990; however, most fishers reported seeing crayfish beginning around 2013. At first impression, most survey respondents reported perceiving crayfish as a threat or being useless. However, many fishers' perceptions later changed to perceive crayfish as useful for food or income, but a sizeable minority continued to view them as useless. In most locations, respondent attitudes toward crayfish either became more positive or stayed the same over time. Fishers reported that most of the crayfish were caught as bycatch, but there were a few fishers specifically targeting crayfish. Catches were highest at Siavonga on Lake Kariba. In terms of utilization, 59% of fishers reported throwing away crayfish, while 41% reported that they sold the crayfish, used them for home consumption, gave them to neighbors, or used them as animal feed. Kafue and Siavonga districts reported the highest levels of crayfish utilization. Negative impacts of crayfish included damage to fishing gear (about 50% of respondents) and damage to fish (over 90% of respondents). Fishers reported crayfish damaging fish by biting them, making the fish watery and tasteless and, therefore, inedible, requiring disposal. Fishers reported they had to fish longer to make up for the discarded fish. Some respondents reported seeing predation of the crayfish by some fish (catfish and tigerfish) and birds (kingfishers), but predation rates remain low.

Fishery Focus Group Discussions

Focus group discussions with fishers yielded additional information about the fishery. They provided validation for many survey responses and made possible discussions with specific groups, including women, youth, crayfish trappers, river sardine (*kapenta*) fishers, and net fishers. The research team conducted focus group interviews from April 27–28 and June 5–9, 2023, in Itezhi tezhi, Sinazongwe, Siavonga, and Chanyanya area in Kafue. There were slightly different impressions at the sites, depending on crayfish abundance and proximity to markets, but key findings at the sites included negative impacts of crayfish on fishers, such as destroying most of the fish catch, crayfish reducing fish population in water, and fish losing taste after being bitten by crayfish destroying the value of the fish. Crayfish abundance in shallow waters may impact more women's fishing efforts (although minor in quantity but important for food security), and women, youth, and older fishers expressed interest in gaining skills to process crayfish into useful products.

Recommendations

Based on the research findings, the team recommends the following:

- Continued collection of scientific data on fecundity, growth, natural and fishing mortality, age structure, and environmental and socioeconomic impacts.
- Engagement in extension education with relevant stakeholders to coordinate early detection and rapid response.
- Stock analysis to determine required fishing effort that would cause recruitment overfishing.
- Actions to protect indigenous species in critical habitat areas (e.g., Lake Tanganyika, Lake Malawi, Okavango Delta).
- Transnational cooperation in the management of capture fisheries. For example, the recently established Kavango–Zambezi Transfrontier Conservation Area can serve as

an excellent forum for coordination of proposed legislation within individual nations aimed at controlling invasive aquatic species.

- The online poll developed by the team should be kept for continued use and disseminated widely to include wildlife officials and the tourism industry. This can present a relatively easy way to continue tracking crayfish presence in Zambia and its neighboring countries.
- Trainings should be conducted to strengthen capacity of different groups (women, youth, and older individuals) with skills to process crayfish for consumption and for animal feed, especially in areas with well-established populations. This may reduce crayfish populations and/or offset some of the negative socioeconomic impacts caused to fishers' livelihoods.

Lessons Learned

Constant communication with all key members of the project on a weekly basis by Zoom helped to identify potential challenges early.

Although the survey instrument developed for this activity was a useful way to collect data on the spread of crayfish, their release does not necessarily rapidly result in many responses. Additional efforts are required, including sending reminders, fostering networks with groups of people with interest in the poll results, and sharing the poll results with responders who have provided their contact information to keep motivation high to answer the poll if it is continued.

Useable Outcomes

1. The activity funded one master's student, who became adept at Electronic Length Frequency Analysis and can be a major asset to fisheries professionals in Zambia going forward.
2. The activity developed a robust dataset describing the current locations of crayfish in Zambia that should aid in policymaking to avoid spread to the Northern and Eastern Regions of the country.
3. Activity findings were transferred to the Zambian Fisheries and Environmental Conservation Departments for their use.

Tangible Impacts

The widespread occurrence of discarding crayfish-damaged fish was discovered, which warrants further exploration to determine the magnitude of the discards, whether additional fishing to make up for losses affects fishers' incomes or fish stocks, and whether increased crayfish consumption offset the loss of damaged fish.

Team members from UNZA continue to maintain the crayfish database as new crayfish sightings occur.

The activity used a four-tiered approach of 1) analyzing fisher-trapped crayfish at critical sites, 2) use of Qualtrics XM to monitor crayfish spread and specifically designing a poll for DoF staff and others who are familiar with Zambian waters, 3) using a socioeconomic survey to assess fishers' perceptions and impacts of crayfish on their livelihoods, and 4) use of focus groups to gauge impacts of the crayfish invasions. This approach could be used individually or in combination to continue monitoring crayfish spread and its impacts on livelihoods. If crayfish monitoring were incorporated into the regular work programming of the DoF and/or the Department of Conservation and Environment as an ongoing budgeted program, management of invasive species could become mainstreamed and institutionalized in Zambia.

Activity 3.6: Strategies for an Inclusive Aquaculture Value Chain in Bangladesh: Analysis of Market Access, Trade, and Consumption Pattern (Market Analysis)

Location: Bangladesh

Lead and U.S. PI: Madan Dey, PhD, Texas State University
U.S. Co-PI: Prasanna Surathkal, PhD, Texas State University
HC PI: Md. Akhtaruzzaman Khan, PhD, Bangladesh Agricultural University
HC Co-PI: Md. Takibur Rahman, PhD, Patuakhali Science and Technology University

Objectives: The overall goal of this activity was to analyze economic implications of aquaculture value chain development in Bangladesh in terms of food security and market access and thus to improve market access for consumers and producers. Specific objectives were as follows:

1. Analyze the food and nutritional security impacts of increased aquaculture production.
2. Evaluate constraints in the aquaculture input markets that influence domestic market access for aquaculture producers.
3. Analyze the export market competitiveness of major aquaculture products of Bangladesh (such as pangasius, tilapia, shrimp, and major carps) for different scale and intensity of farming operations.

Executive Summary: Fish is the most frequently consumed animal-source food in Bangladesh, though its intake considerably varies between different household groups. Over the last several decades, the share of aquaculture in overall fish production in the country has been rising, while that for capture fisheries has been declining. However, all farmers, fishers, and traders do not have similar access to key inputs. In addition, the COVID-19 pandemic has wreaked havoc on the aquaculture and fisheries sectors in the country. Additionally, Bangladesh is losing shrimp export competitiveness.

Therefore, the activity aimed to analyze the economic implications of increased aquaculture production in terms of food security and market access based on data obtained from a primary survey and secondary sources.

Analysis of the Bangladesh National Income Expenditure Survey Data from 2000 to 2016 revealed that fish consumption has increased over the studied period for every category of household—rural, urban, and all income quantiles. However, the lowest income quantile (i.e., the poorest households) has experienced the fastest growth in fish consumption. Cheaper, cultured fish species are highly demanded by the lowest income quantile, whereas high-value, cultured and captured fishes are mainly consumed by households in the upper-income quantile. The findings indicate that aquaculture is contributing to improving fish consumption patterns irrespective of income groups and the residential status of households, including the lowest income quantile. Conversely, with the limited availability of captured fish, there has been a notable rise in prices, hence impacting the accessibility and consumption of many nutritious, micronutrient-rich fish among the poorest households.

Results in relation to trade credit indicate that users are as technically efficient as non-users. Trade credit enables farms to use improved production technology with a positive trade-off between benefits and costs. Convenience, interest rate, collateral, documentation, number of suppliers, and revenues influence trade credit decisions. The trade credit supports farms' continuity and adoption of the best technology in the industry.

Among the price factors, increases in the price of corn, soybean, and oilcake as well as wage rates significantly increase fish prices in both the short and long term. Among the non-price drivers, Gross Domestic Product (GDP) per capita, inflation rate, and fish consumption all have a significant positive influence on fish prices in the long run; however, increases in total

production decrease fish prices in the long run. A higher feed price is a major constraint to aquaculture in Bangladesh, particularly for poor farmers. Policies aimed at promoting domestic production of key ingredients for fish feed have the potential to decrease import dependency, resulting in reduced production costs and lower fish prices.

The findings indicate that income and employment across the value chain were severely affected by the COVID-19 pandemic, with a drastic fall in the market demand coupled with a severe drop in fish consumption. As market demand declined, fish farmers had to extend the culture period, eventually increasing the cost of production. The price of all the major cultured and captured species declined, and return to farmers decreased, while input prices increased significantly except for labor and fingerlings. The main obstacles facing the aquaculture industry during the COVID-19 pandemic included higher transportation costs, labor shortages, inability to pay wages, and reduced consumer demand.

Bangladesh, China, India, Indonesia, Thailand, and Vietnam all had some degree of shrimp export competitiveness from 1990 to 2019, but China has entirely lost its export competitiveness since 2004. Bangladesh's shrimp export competitiveness has dipped marginally in recent years, despite continuous growth in competitor countries. Economic globalization, institutional quality, trade openness, number of trade agreements, and trade freedom positively influence the long-run shrimp export competitiveness; the international or exporting price of shrimp has a detrimental influence both in the short- and long-run.

This activity was implemented in collaboration with related stakeholders in the country, including the Ministry of Planning of the Government of Bangladesh, BFRI, and DoF. The activity ended with a day-long policy workshop, with more than 170 invited national and international participants and stakeholders from the relevant ministries, institutions, and organizations. Relevant government agencies have agreed to incorporate the activity’s recommendations in various policy documents, including the National Fisheries Policy, which is being revised currently. These recommendations are:

- Technological advancement across the value chain (farm and processing levels) is needed for improving quality, taste, traceability, and acceptability of the popular fish species and fish products.
- Enhance capture fisheries, particularly for species enriched with micronutrients.
- Promote community-based fish farming in floodplains during the rainy season with the participation of all relevant stakeholders, including poorer households who captured small fishes from floodplains in the past.
- Policies supporting more trade finance may improve access to more quality inputs and markets.
- Buffering stock strategy and domestic production for/of major feed ingredients may help reduce the cost of production of fish.
- Improving infrastructure is needed for value-added inbound and outbound logistics.
- Reducing financial and nonfinancial trade barriers and fish branding are important for increasing export of fish.

Lessons Learned

1. Active participation of relevant stakeholders and policy makers is essential for ensuring activity success and institutionalization of policy recommendations.
2. A holistic approach considering various subsectors of aquaculture and fisheries is needed. Future aquaculture policies should make positive trade-offs between capture

fisheries and aquaculture. Capture fisheries is declining, which has severe impacts on nutrition intake of poor and vulnerable groups.

3. Networking and linkages with diverse value-chain actors, including feed manufacturers, processors, and exporters, are extremely important for sustainable aquaculture growth. Beneficial changes include 1) access to institutional credits for suppliers, 2) alternative international markets for increased production, which requires standard production practices for quality fish, and 3) more technological investment for improving traceability in fish and fish products. Fish product branding strategies also can play an important role in enabling entrance into high-value global markets.

Useable Outcomes

1. Results on input markets, output markets, and contribution of aquaculture growth to food and nutrition security were disseminated among policy makers, industry operators, academicians, and researchers to guide their future sectoral policies, operating decisions, academic programs, and research agendas.
2. Farm operators who participated in the activity training sessions improved their knowledge of farm business management.
3. Information on Bangladeshi shrimp competitiveness and its factors will help policy makers and industry operators position Bangladeshi shrimp competitively in the international market.
4. Findings from the COVID-19 impact analysis will guide future policies focused on successful recovery strategies for the aquaculture sector from the pandemic and similar future shocks.
5. Market analysis provided important insights to develop effective strategies for improving access to inputs, especially credit and feed ingredients, and controlling fish price.

Tangible Impacts

The activity enhanced the human and institutional capacities of partner institutions, including a more inclusive and gender-sensitive approach to aquaculture research and policy development in the country. These factors can contribute to the growth of aquaculture production, leading to an increase in the country's export earnings and a subsequent rise in the aquaculture sector's contribution to the GDP. Additionally, this can result in higher revenue for farmers, value-chain actors, and exporters, which will improve the food and nutrition security of people in Bangladesh.

The activity followed a collaborative approach, involving all key stakeholders (including Ministry of Planning of the Government of Bangladesh, DoF, BFRI, fish farmers/traders/consumers, and various universities) during the formulation and implementation of the research. The State Minister of Planning was actively involved in the activity's formulation, implementation, and final policy workshop. This will ensure that the activity's recommendations are incorporated in relevant sectoral and national polices to achieve long-term impacts.

Activity 3.7: Micronutrient Impact of Oysters in the Diet of Women Shellfishers (Micronutrient Impact of Oysters)

Location: Ghana

Lead and U.S. PI: Brietta Oaks, PhD, University of Rhode Island
HC PI: Seth Adu-Afarwuah, PhD, University of Ghana

Objectives: The research objectives were to

1. Determine the contribution of oyster consumption to iron and zinc intakes of women shellfishers.
2. Determine whether there is any variation in iron and zinc content of oysters across the three study sites in Ghana.
3. Investigate whether heavy metal contamination is a concern in the three study sites in Ghana.
4. Provide guidance for public health authorities, women's shellfish associations, and other stakeholders.

Executive Summary: In Ghana, oyster shellfishing offers a rich source of iron and other nutrients for women shellfishers who engage in oyster harvesting, processing, and marketing. Little is known about the level of oyster consumption among women shellfishers and the extent to which oysters contribute to women's iron and zinc intakes. Additionally, data on the heavy metal contamination of oysters in Ghana are limited. This activity aimed to examine nutrition outcomes including food intake, food insecurity, dietary diversity, and anemia prevalence among women shellfishers in three estuarine areas in Ghana. The research team also aimed to determine the mineral and heavy metal concentrations of oysters from each of the three sites and to analyze the safety risks posed to the women shellfishers of reproductive age by arsenic, cadmium, lead, and mercury related to the consumption of oysters.

Methods

The team conducted a cross-sectional study among 504 women shellfishers living near three oyster estuarine sites along the coastline of Ghana. The three sites were 1) the Densu (highly degraded mangrove ecosystem and underexploited fisheries health status), 2) Narkwa (moderately degraded mangrove ecosystem and overexploited fisheries health status), and 3) Whin (less degraded mangrove ecosystem and fully exploited fisheries health status). The team collected information on the women's demographic and socioeconomic characteristics, household food security, and dietary intake. The researchers determined anemia prevalence by collecting a drop of blood by fingerprick for each woman and using an instant reading device to determine hemoglobin concentration, which is often a proxy indicator for iron deficiency. Across estuarine sites, the team examined average oyster consumption and its relationship with nutrient intakes (including iron intake from oysters), household food security, diet diversity, and anemia prevalence. The team measured the mineral and heavy metal concentrations of 915 oysters collected from the three estuarine sites and evaluated the potential health risks of exposure to heavy metals (arsenic, cadmium, lead, and mercury) by calculating the HI for oyster consumption among women shellfishers, with an HI above 1 indicating a health risk concern.

Results

The average age of 32 (± 9 years) was generally similar for women across sites, and socioeconomic status (indicated by wealth-poverty score) was higher among Densu and Whin women than among Narkwa women. This reflected broader trends in the communities, with 63% of Densu households and 65% of Whin households reporting higher socioeconomic status compared to 37% of Narkwa households. Only 12.5% of the women shellfishers reported consuming any oysters when asked about dietary intake for the previous day on two different days. Oyster consumption was higher among women from Densu and Narkwa than women from Whin. Iron intake from oysters was significantly higher among the Densu women (0.4±1.3 g/day) than the Whin women (0.02±0.20), with that for the Narkwa women (0.3±1.7) not significantly different from the other sites. Approximately 92% of women reported some form of household food insecurity, and the prevalence of severe food insecurity ranged from 72% in the Densu to 85% in Narkwa. A total of 20% of the women had anemia, and only 21% achieved

dietary diversity.

The oysters differed significantly across the sites in the concentrations of the 17 minerals and heavy metals measured. Iron concentration was highest in the oysters from Narkwa (147±142 mg/kg wet weight) and lowest in the Whin (103±87 mg/kg wet weight). None of the oysters exceeded the maximum concentration limit for arsenic, cadmium, lead, or mercury, except for one oyster sample from the Narkwa site, which exceeded the maximum concentration limit for mercury. The average cumulative HI for oyster consumption among the women shellfishers ranged from 0.04 at the Whin site to 0.13 at the Narkwa site; none of the estuarine sites had an average HI exceeding 1. At all three sites, the primary driver of the HI values among the women shellfishers was mercury followed by lead.

Conclusion

The level of oyster consumption among the women shellfishers at the three estuarine sites in Ghana may be too low to make any substantial impact on the women's iron and zinc intakes from oysters. More research is needed to explore how women living in estuarine areas in Ghana might use shellfishery resources to prevent anemia. Heavy metal contamination does not appear to pose a major health risk for the women shellfishers related to oyster consumption. Promoting oyster consumption may be a promising strategy to increase nutrient intakes and prevent anemia in estuarine communities. There should be regular monitoring of mercury and lead contamination of oysters and other aquatic animal foods, especially at the Narkwa area.

Lessons Learned

Analyzing 24-hour dietary recall data for women shellfishers in Ghana was challenging, primarily because a reliable food composition table was not readily available. The team solved this challenge by supplementing a food composition table previously used for research in Ghana with data from FAO's West African Food Composition Table and the United States Department of Agriculture.

Useable Outcomes

Usable outcomes generated by the activity include

- Data on dietary intakes, including oyster consumption, among women shellfishers at three estuarine sites along the coastline of Ghana.
- Mineral concentrations (including macro-minerals, trace elements, and heavy metals) of oysters from three estuarine sites along the coastline of Ghana.
- Analysis of the extent of heavy metal contamination of oysters from three estuarine sites along the coastline of Ghana.

Tangible Impacts

The long-term impact of the activity is the awareness that oysters could provide a rich source of dietary minerals to many people in coastal communities. This awareness could inform calls for increased consumption of oysters in these communities, particularly among women shellfishers, who currently consume low amounts of oysters.

Associate and Buy-In Awards

Supporting USAID Missions by Conducting Complementary Research and Learning Related to Distant Water Fleets in Fisheries

Location: Madagascar, the Pacific Islands, the Philippines, and Peru

Lead and U.S. PI: Elin Torell, PhD, University of Rhode Island
U.S. Co-PI: Austin Humphries, PhD, University of Rhode Island
U.S. Co-PI: Rachel Zuercher, PhD, University of Rhode Island
U.S. Co-PI: Lauren Josephs, University of Rhode Island

Objectives: The Fish Innovation Lab received a buy-in award at the end of FY21. This award from the Bureau for Development, Democracy, and Innovation supported the ongoing USAID Distant Water Fleet (DWF) Research Agenda on responsive actions related to the drivers and impacts of DWF on national fisheries and fisherfolk in priority USAID geographies.

The research goals were to

1. Explore transparency and sustainability in licensing and supply chains associated with DWF activity in select national exclusive economic zones.
2. Characterize the scale, form, and socioeconomic impacts of DWFs on national fisheries and fisherfolk in select geographies.

Executive Summary: DWFs are vessels that fish far from their home waters, often within the national waters of other countries, especially countries with developing economies. Industrial DWFs have been identified by USAID as one of many challenges to recovering or sustainably managing fish stocks that can be mitigated through broader efforts to improve scientific, governance, and enforcement capacities. More recently, some USAID Missions have identified DWFs as a direct and significant impediment to improving the management of national fisheries and are beginning to consider targeted interventions to counter the impacts of DWFs on fishery resources. DWFs represent a significant portion of global, wild fisheries landings and are known to engage, in some cases, in harvesting practices that are legal but unsustainable or unjust. Some DWFs also engage in illegal, unregulated, or unreported fishing. Through such activities, these heavily subsidized fleets decrease fish availability for small-scale fishers, reduce revenue to local economies, and diminish opportunities for fisheries to address domestic food and nutrition needs. DWFs also represent a significant source of revenue for some host nations via fishing access agreements.

Under the direction of the USAID DWF Research Agenda, the research team explored a wide range of relationships between DWFs and local food and nutrition security, pathways by which DWFs may affect food security and the extent of those effects, and how shifts in fisheries management could influence food security. To do this, they analyzed four fisheries, each landed by both domestic fleets and DWFs: roundscad (galunggong) in the Philippines, neritic tunas in Madagascar, jumbo flying squid (pota) in Peru, and skipjack tuna in the Pacific Islands region. The research used mixed methods and drew from existing datasets on fish landings, nutritional content of fish, national-level nutrition indices, and key informant interviews regarding the interactions between DWFs and domestic fleets. Aquatic foods contain high levels of micronutrients and vitamins that are essential for human health and wellbeing. Nutrients such as calcium, iron, and omega-3 fatty acids are often lacking in diets, but they are present in bioavailable forms in many types of seafood. Fishery contributions to domestic food and nutrition security are mediated by factors such as fish availability in coastal waters, people's access to and the affordability of fish, and species-specific nutrient profiles. Thus, a fishery can influence food and nutrition security both via people's direct consumption and through income and revenue flows related to domestic and foreign fishing (e.g., access agreements).

By developing detailed descriptions of the four case study fisheries, the researchers showed that fish currently exported by DWFs represent the nutrition needs of substantial numbers of women and children, demographic groups at higher risk of negative consequences resulting from a lack

of access to healthy diets. If consumed in host countries by people experiencing food insecurity, stunting, or malnutrition, those fish could provide real and substantial health benefits. However, cultural norms surrounding seafood consumption, physical and economic access to seafood by the most food-insecure individuals in a population, degraded status of fish stocks, and supply-chain infrastructure all serve (in various cases) as impediments to realizing the full potential of local fish resources. Bolstering the case for increased attention to this issue, the researchers also found strong evidence that DWFs are contributing to overexploitation of fish stocks that domestic small-scale fleets are heavily dependent on. Finally, the case studies showed instances where DWF landings were being sold in local markets and thus are likely improving people's food security via income pathways, highlighting the diversity of ways by which DWFs are affecting food and nutrition in host countries.

The four case studies exemplify complex relationships between DWFs, local catches by domestic small-scale fleets, employment and income in the fishery sector, and access to fish as a healthy food source. The diverse pathways by which DWFs impact food and nutrition security underscore the importance of nuanced and place-based policy interventions to improve food security via the management of DWFs. While strengthening enforcement of illegal, unregulated, or unreported fishing may provide benefits in one place, limiting or excluding DWFs may be the best approach in another location. Alternatively, working within existing foreign access agreements to mandate the availability of a portion of DWF landings to local communities may be the most direct route to improved food security. Many policy levers exist by which to promote food security through the improved management of DWFs, and decision-makers should consider ecological, social, and economic dimensions of any fishery before designing policy.

Lessons Learned

The relationships between DWFs and food security are part of a larger story that includes labor rights in the fishing industry, the health of marine ecosystems, and injustices of the global economic system and DWF fishing. Considering implications for people's food security alongside other globally important issues related to DWF fishing will serve to promote sustainable and just fishery systems for the benefit of people and nature.

Human and Institutional Capacity Development

Human and Institutional Capacity Development Activities

Human and institutional capacity development (HICD) is a critical component of the Fish Innovation Lab, which strives to catalyze local leadership, research excellence, and capacity. During Phase 1, all Fish Innovation Lab-funded subawards included activities to strengthen capacity of local partners, students, extension services, and broader stakeholders. The strategy included traditional classroom and online training, mentoring, partnering, and "learning by doing" models founded in collaborative research. Activities contributed to U.S.-based and in-country researcher engagement and formation of an aquaculture and fisheries community of practice. Long-term, hands-on, graduate training of students was emphasized in partner countries. As a result, 43 students (of which 33% were females) engaged in long-term training. Furthermore, stakeholders, community members, and end-users were engaged through short-term trainings and direct involvement in research activities. In FY23, 1,641 individuals (with 30% female representation) participated in short-term trainings. Notable HICD accomplishments included:

- The **ME capacity development specialist** established a Fish Innovation Lab student network. A total of 30 students participated in five virtual meetings led by senior researchers on the topics of presentation skills, managing relationships with advisors,

leadership within a university setting, mixed methods in data collection, and contributions of fish to human nutrition.

- The **ME gender and youth equity specialists** led or participated in more than 30 activities designed to promote or contribute to capacity development, including technical reports, conference sessions, trainings, and highlighting research on digital platforms and media outlets. They produced three online certification courses that enrolled more than 601 learners and awarded more than 170 certificates.
- The Bangladesh **Harnessing Machine Learning activity** invested heavily in capacity development. The team trained 91 Bangladesh and 45 international participants on remote-sensing methodologies for fishpond identification through an online course of six 45-minute tutorials and four live question-and-answer sessions. The activity produced 13 short extension videos on innovative practices in the aquaculture value chain in southwest Bangladesh reaching 10,107 people on Facebook and YouTube. The team also completed three outreach workshops with 146 participants from government, nonprofit organizations, and the private sector in Dhaka, Gopalganj, and Khulna, receiving extensive national and local media coverage. These workshops received strong buy-in from the DoF, which hosted the Dhaka event at its headquarters, ensuring a high level of attendance by key DoF staff. The DoF endorsed the machine learning approach to estimating aquaculture production indicators and expressed interest in incorporating the approach into DoF practices. The activity ended in September 2022, but following the final activity workshop, the DoF website tagged the activity's online interactive aquaculture database as a decision-making platform/tool on its homepage navigation bar (see "Online Fisheries statistics" at http://www.fisheries.gov.bd/).
- The Bangladesh **Cryogenic Sperm Banking activity** trained more than 550 stakeholders (more than 30% youth and female) including hatchery managers and operators, nursery operators, fish farmers, scientists from BFRI, government officers of the DoF, NGO personnel, junior faculty members, and three PhD and four master's students in a series of 14 workshops in the Mymensingh, Faridpur, Jashore, and Barishal regions of Bangladesh. The trainings covered sperm cryopreservation techniques, fish breeding using cryopreserved sperm, and growth performance of cryopreserved sperm-originated seeds. Training materials and video documentaries were developed and can be used to train future stakeholders. Research team members participated in a 2-week-long advanced training through AGGRC and LSU AgCenter. The activity developed cryogenic sperm banks at BAU and bred six carp species using cryopreserved sperm in four regions resulting in 28 hatcheries successfully producing seeds. The activity's stakeholder engagement and capacity development across government, private sector, farmers, and academia combined with the positive initial technical results of improved seed growth are key elements that can drive a robust ecosystem of producers and service providers for adoption of this technology going forward.
- The Bangladesh **Foodborne Pathogens activity** provided intensive training to personnel from the government's fisheries and food safety laboratories. The fisheries laboratory is primarily responsible for testing all types of fish destined for export. Increasingly, they are also involved in conducting surveillance of fish samples from local markets. The laboratory applied the training to begin genetic detection of major foodborne pathogens for the first time, putting new skills into practice and demonstrating the capacity to respond to a long-standing demand from consumers for this type of testing. The laboratory plans to expand this service for other important fish pathogens.

- The Nigeria **Improving Biosecurity activity** hosted a workshop in August 2022 on catfish and tilapia disease that increased capacity of 109 aquaculture stakeholders from the Federal Ministry of Agriculture and Rural Development, the Nigerian Agricultural Quarantine Services, Oyo and Ogun State public and private veterinary services, private aquaculture groups, academics, and the media. The E-AquaHealth diagnostic extension platform established at UI for farm cluster leaders, resident veterinarians, and university researchers enhances prompt response to disease outbreaks and supports fish farmers (https://ohrg-unibadan.org/aquahealth/). The activity identified a gap in laboratory capacity and field sample collection, transport, and processing using continuous aseptic conditions for the primary culture of key bacterial pathogens, as well as transportation and integrity of biological samples between partner labs in multiple countries. The activity further strengthened stakeholder capacity to apply activity innovations through development of a manual on better management practices for catfish farmers and a stakeholder engagement workshop on "Better Management Practices in Aquaculture and E-technology Platform Adoption for Sustainable Aquaculture Development in Nigeria" in May 2023.
- The Nigeria **Lean Production Systems activity** resulted in 40 Lean experts trained, 265 projects implemented in 213 small and medium farms, and active farmer engagement via social media channels. Findings demonstrate the ability of Lean management practices to advance the Nigerian aquaculture sector and individual farmers to drastically reduce waste and increase profitability.
- The Nigeria **Aquaculture Diversification in Rural Communities activity** trained more than 700 farmers how to adapt rice fields to integrate fish culture using technological packages developed by the team. The activity supported farmers to sustain the increased productivity of their farms and learn additional management techniques through a participatory farmer field school. Institutional demonstration farms at UDUS and UI will enable ongoing student training and increased capacity to support and scale the technology. Faculty and staff from UDUS and Michael Okapara University of Agriculture Umudike who were trained in fish seed production along with farmers and hatchery operators from Kebbi and Ebonyi States further increased their capacity to support farm diversification technologies.
- The Nigeria **Nourishing Nations activity** training and low-literacy customer outreach tools enabled fish processors to increase their knowledge on food safety and nutrition, grow their businesses, increase market share, and improve and diversify product lines. As a result of the training, fish processors began organizing into business cooperatives.
- The Kenya **Samaki Salama activity** educated fishers on sustainable fishing practices and caregivers on appropriate child feeding practices. The activity demonstrated the benefits of gated traps to reduce the catch of juvenile fish and increase fish catch weight and value. Community health volunteers, a cornerstone of Kenya's healthcare system, were trained and provided learning materials and teaching aids on appropriate child feeding practices, care-seeking practices, and hygiene and sanitation, as well as how to conduct home visits, assess the health and nutritional status of children, and offer more nutrition education support to caregivers with challenges. The community health volunteers also learned appropriate cooking methods and how to conduct cooking demonstrations. The activity trained fish data collectors and other BMU officials on sustainable fishing practices and collecting fish catch data.
- The Kenya **Coral Reef Fishery Sustainability activity** mobile app supported training of 12 data collectors, who are members of BMUs, and county fisheries officers to monitor

fish landings by recording fish landed by fish family and fishing effort to increase awareness, inform stakeholders on reef status and community capacity, and make recommendations to relevant bodies. A comparison of trained fisheries officers' and community members' collected data showed that communities can conduct successful monitoring. Participatory mapping enabled 90 BMU members and county fisheries officers to gain knowledge and skills to produce and validate hand-drawn and digitized maps of fishing ground landmarks and fishing zones. The exercise led to the realization that some fishers were still fishing within the Locally Managed Marine Areas or Marine Protected Areas. Forty-five individuals from five communities gained knowledge on how to identify fish species and evaluate fish biomass in eight sites within the Vanga - Shimoni seascape area. The activity produced underwater video clips and recorded video presentations on the current status of Shimoni-Vanga seascape fisheries and developed a fish biomass training manual in Swahili and English to be used for future reference.

- The Citizen Science Fisheries Harvest Assessment program from the **Cambodian Fisheries and Food Processing activity** trained local fishers who collected accurate data on the status of the Sre-Ambel River fisheries over 2 years, resulting in individual capacity development, buy-in for sustainable monitoring of fisheries, and empowerment of fisheries communities.
- The **Zambia Crayfish activity** documented that invasive crayfish populations were robust with multiple age classes present and that they appeared in seven previously unreported locations in the Zambezi River basin, including in the Kwando sub-watershed of the Zambezi Basin in the Western Province that borders with Angola, which has a seasonal aquatic connection to the critical Okavango Delta Wildlife Refuge in Botswana. These datasets were transmitted to the Zambian Fisheries and Environmental Conservation Departments and should aid in policymaking to avoid spread to the northern and eastern regions of the country.

Short-Term Trainings

During the FY23 reporting period, a cumulative total of 1,641 individuals received short-term training across various categories. Within this group, 1,144 were male, and 497 were female. Most of these trainings occurred during the first half of the fiscal year. Notably, producers made up 69% of the overall participant pool, demonstrating the Fish Innovation Lab's commitment to fostering technological advancements and adoption. Details are provided in Appendix 2, Short-Term Trainings.

Long-Term Trainings

The Fish Innovation Lab's commitment to nurturing talent and fostering the development of the next generation of researchers and experts is evident in its sustained efforts to provide long-term training opportunities. These programs not only contribute to the professional growth of participants but also have a broader impact on the advancement of research and innovation in aquaculture and fisheries for partner institutions and countries. In FY23, the Fish Innovation Lab continued to make significant investments in building the capacity of individuals across various academic levels, including undergraduate, graduate, and PhD students as well as postdoctoral researchers. This commitment to long-term training has been a cornerstone of the Fish Innovation Lab's efforts to advance research and innovation in the fields of aquaculture and fisheries.

In FY23, 32 individuals continued their long-term training from the previous year. These individuals represent a diverse group of learners who have been actively engaged in capacity-

building activities through the Fish Innovation Lab's programs. FY23 also marked the inclusion of 11 new individuals in long-term training programs. These newcomers joined the Fish Innovation Lab's efforts to expand the pool of experts and researchers dedicated to advancing knowledge in aquaculture and fisheries. By the end of FY23, a total of 43 individuals (29 male and 14 female) had successfully completed long-term training programs facilitated by the Fish Innovation Lab. These individuals have acquired valuable skills and expertise that will contribute to continued growth and innovation within the aquaculture and fisheries sectors. Details are provided in Appendix 2, Long-Term Trainings.

Implementation of Other Cross-Cutting Themes

In Phase 1, the Fish Innovation Lab had four cross-cutting themes: gender equity and youth engagement, nutrition, resilience, and capacity development. The importance of integrating cross-cutting themes is gaining increasing acknowledgement within the broader Feed the Future Innovation Lab community. The Fish Innovation Lab participated in the Innovation Lab Community of Practice on cross-cutting themes (gender and capacity development). Fish Innovation Lab Deputy Director (2018–2022) Elin Torell participated in the Community of Practice steering committee, and Fish Innovation Lab Gender and Youth Equity Specialists Kathleen Ragsdale and Mary Read-Wahidi engaged in the gender affinity group. Highlights related to capacity development were summarized above; highlights related to gender and youth, nutrition, and resilience are summarized below.

Gender Equity and Youth Engagement

The Fish Innovation Lab gender equity and youth engagement theme was led by Kathleen Ragsdale and Mary Read-Wahidi. They supported subaward activities by providing overall guidance to develop gender-responsive programming. They promoted the importance of gender-transformative and youth-inclusive agricultural development through more than 40 gender- and youth-related activities, with a focus on high-impact and open-access resources as well as collaborations with other Fish Innovation Lab cross-cutting themes and across Innovation Labs. Key examples include:

- Developing the online certification course “Gender Impacts Lab Toolkit: How to Build Your Own GRADA (Gender Responsive Agricultural Development Assessment),” which was jointly sponsored by the Feed the Future Innovation Lab for Soybean Value Chain Research, Fish Innovation Lab, and the Gender Impacts Lab at MSU.
- Developing the online certification course “Your Comprehensive Guide to Conducting Focus Groups in Village Settings for Gender-Responsive Agricultural Development,” which was jointly sponsored by the Fish Innovation Lab, Feed the Future Innovation Lab for Soybean Value Chain Research, and the Gender Impacts Lab. Since the course was launched in September 2022, more than 109 learners enrolled, and 21 certificates were awarded.
- Delivering the invited presentation “Using the GRADA to assess gender-responsive agricultural development across IL projects” as part of the Summer (Back to) School Series Webinar hosted by the Resilience and Food Security Community of Practice.
- Jointly organizing the virtual workshop on “Integrating Gender Throughout the Project Life Cycle of Innovation Labs” for the Feed the Future Innovation Lab Community of Practice.
- Jointly organizing, with Fish Innovation Lab Nutrition Specialist Lora Iannotti, the 2022 American Public Health Association session “Role of Fish in Mitigating Food Security and Nutrition Gaps among Vulnerable Populations in Developing Countries: Evidence

Across Sub-Saharan Africa," which featured results from Fish Innovation Lab-funded activities.

Fish Innovation Lab communications and outreach initiatives on this cross-cutting theme included more than 12 blog posts for Agrilinks and the Fish Innovation Lab website. A few key examples are highlighted below. See Appendix 7 for a comprehensive list of presentations and publications.

- Zseleczky, L. "Working from the Inside Out: How the Fish Innovation Lab Helps Partners Integrate Gender in Their Activities." Agrilinks, March 29, 2022, https://www.agrilinks.org/post/working-inside-out-how-fish-innovation-lab-helps-partners-integrate-gender-their-activities. (Cross-Cutting Themes: Gender Equity and Youth Engagement, Capacity Development)
- Ragsdale, K., Read-Wahidi, M. R., Torell, E. "New Tool Helps Quantify Post-Harvest Losses in Small-Scale Capture Fisheries." Feed the Future Innovation Lab for Fish, February 1, 2022, https://www.fishinnovationlab.msstate.edu/newsroom/2022/02/new-tool-helps- quantify-post-harvest-losses-small-scale-capture-fisheries. (Cross-Cutting Themes: Gender Equity and Youth Engagement, Nutrition, Capacity Development)
- Brasher, K. "MSU Feed the Future Projects Gain Global Attention at Borlaug International Dialogue." Mississippi State University, November 4, 2021, https://www.msstate.edu/newsroom/article/2021/11/msu-feed-future-projects-gain-global-attention-borlaug-international. (Cross-Cutting Themes: Gender Equity and Youth Engagement, Nutrition)
- Agrilinks. "Gender mainstreaming in fisheries and aquaculture sectors." Agrilinks, June 25, 2021. [A version of this post was originally authored by K. Ragsdale, M. Read-Wahidi, and E. Torell and posted on the Fish Innovation Lab website on March 29, 2021] https://www.agrilinks.org/post/gender-mainstreaming-fisheries-and-aquaculture-sectors

The Fish Innovation Lab administered Wave I of the Gender-Responsive Aquaculture/Fisheries Development Assessment for the Fish Innovation Lab (GRADA-FIL) in October 2020 and WAVE II from December 2022 to January 2023. GRADA-FIL surveys were administered to all active Fish Innovation Lab subawardees and assisted in advancing gender-responsive aquaculture and fisheries programming. Because activities were drawing to a close at the time of WAVE II survey administration, the subawardees were well-positioned to reflect on gender barriers they encountered throughout implementation. Findings from the WAVE II survey included the following:

- Regarding increasing women's participation in the aquaculture/fisheries value chain to be more on par with men, 54% of participants reported that their research team successfully increased women's participation in aquaculture/fisheries trainings, 41% reported successes in increasing women's participation in aquaculture/fisheries programs, and 36% reported successes in increasing women's access to aquaculture/fisheries resources.
- Regarding aiming to work specifically with women while not excluding men, 57% of participants reported successes in recruiting women university students to join their research teams, 41% reported successes encouraging extension services to reach more women, 39% successfully worked with women entrepreneurs and/or women's associations, and 36% successfully worked with women fishers.
- Regarding the collection and dissemination of gender-disaggregated data, 61% of participants reported that their team successfully collected data on the number of men

and women who participated in activities, 50% reported successes in collecting data on the number of men and women who received resources, inputs, or technologies, and 43% reported successes in addressing gender issues when reporting results and making aquaculture/fisheries policy recommendations.

- Forty-seven percent of participants reported challenges identifying leverage points to increase women's participation in aquaculture/fisheries trainings, 37% reported challenges identifying leverage points to increase women's participation in aquaculture/fisheries programs, 33% reported challenges identifying leverage points to increase women's access to aquaculture/fisheries resources, and 27% reported challenges identifying leverage points to increase women's production and/or income.

The results of the GRADA-FIL internal assessment demonstrated that successes and challenges across activities were not necessarily mutually exclusive. Although respondents frequently reported successes in areas such as identifying leverage points to increase women's participation in aquaculture/fisheries trainings, determining which gender issues to highlight when reporting results and making aquaculture/fisheries policy recommendations, and increasing women's participation in aquaculture/fisheries programs, these were also the most frequently reported challenges. This also indicates that successes are often only achieved after overcoming a set of challenges.

It is notable that over 50% of respondents reported successes in three categories. Because gender equity is one of the Fish Innovation Lab cross-cutting themes, grantees were required to have gender mainstreaming components built into their proposals from the onset. The consistently higher rates of successes versus challenges seen in the above results speak to the effectiveness of this approach.

Gender equity and youth engagement results included several activities with strong gender components targeting women as consumers and as producers of fish products:

- The **FishFirst! Zambia activity** focused on improving nutrition among vulnerable households, particularly for rural women of reproductive age and infants and young children (6–23 months). By furthering knowledge of nutritional benefits of dried fish powder and developing/testing ComFA+Fish products/recipes for these groups, the activity improved gender equity in nutrition. By promoting the inclusion of women and youth entrepreneurs in ComFA+Fish scale-up, the activity improved gender and youth equity in and resilience of fish value chains and households.
- The Nigeria **Nourishing Nations activity** trained women (72% of participants) on fish processing techniques and business skills to strengthen women's capacity as strong economic actors in the fish processing sector. Processors strengthened their technical skills in producing high-quality, safe, and nutritious processed fish products for local consumption and strengthened their business skills in marketing their products. Many planned to use the knowledge and practical experience gained to develop business plans to enhance productivity and expand their businesses. Women and youth fish processors in Delta State began organizing into business cooperatives with support from training facilitators and activity team members because of the training they received. Women and youth fish processors reported frequent use of the low-literacy tools developed by the activity for educating customers and the general public on the benefits of fish consumption for human nutrition. These tools increased knowledge among women fish processors about proper nutrition and empowered their decision-making ability on business practices.

- The Kenya **Samaki Salama activity** targeted both fathers and mothers of young children (both male and female) for social marketing around the importance of fish nutrition and sustainable fisheries. Youth are also among the small-scale fishers and mothers of young children.
- The Ghana **Micronutrient Impact of Oysters activity** addressed a research gap on the nutrition of women shellfishers. This research activity measured anemia, which disproportionately affects women. The activity also studied women's dietary intake to determine how oysters may be part of the solution to reduce anemia by providing iron to their diet. By confirming there is no heavy metal contamination of concern in oysters, the research established a foundation on which oysters can now be promoted to address nutritional deficiencies. The findings can benefit the health of women and can benefit them financially as shellfishing, a woman-dominated activity, should be encouraged and supported.

Gender equity and youth engagement results also included:

- The Nigeria **Aquaculture Diversification in Rural Communities activity** reached 727 beneficiaries, 32% of whom were women and 7% were youth. Some interventions were directed toward robust youth engagement in the aquaculture value chain and were tailored to ensure youth access to knowledge, information, and education. These interventions were related to productive land use, extension services, and mentorship, and they had up to 82% youth participation.
- The **Farming Insects in Nigeria activity** prioritized all interested women and youth for the BSFL meal feed trials and establishment of BSF colonies because women and youth candidates were very few in the target zones, where aquaculture production is dominated by men over 31. This effort proved to be effective in attracting youth, as 72% of project participants were aged 15 to 29 years.
- The Nigeria **Lean Production Systems activity** engaged women and young innovators in training efforts. Among the 265 overall participants in training activities, 20% were women, 10% of participants were under 31 years old, and 44% were between 31–43 years old. Data showed that women were good adopters of Lean management, as were their male counterparts, and that they could help scale the technology.
- The Bangladesh **Foodborne Pathogens activity** found that in retail markets in Dhaka, Bangladesh, the proportion of female vendors was very low, but many of the men were youth. The team prioritized and included 42% youth (90% of whom were retail or wholesale vendors) in its study of behavioral practices (fish transportation, storage, and quality of water used in fish storage). Youth have more opportunities to learn and adopt future interventions and were more enthusiastic about participating in the interviews. At the activity's final year workshop on Risk Analysis in the Regulatory Process, approximately 25% of the trainees were female, promoting gender diversity in the food safety domain. A significant 68% of the participants were below the age of 35, reflecting the engagement of young professionals in this field. During the activity's short-term training period, the team trained one female microbiologist from the government fisheries lab who played a key role in testing fish samples for different microbiological parameters for regulatory purposes.
- The Bangladesh **Harnessing Machine Learning activity** developed possibly the most detailed picture of gendered employment in aquaculture value chains ever completed by collecting very detailed data on women's, men's, and youth employment by activity and labor source in five segments of the aquaculture value chain. The activity also utilized a

version of the Women's Empowerment in Agriculture Index in its farm survey, modified to fit the context of aquaculture in Bangladesh.

- The **Cambodian Fisheries and Food Processing activity** included 56 men and 44 women who completed surveys, and 55 women and 45 men who participated in sensory panels. Nutrition trainings were designed to have a strong component focused on resilience of value chains and households through training participants on potential income-generating microenterprise opportunities for women and youth entrepreneurs.
- The Kenya **Coral Reef Fishery Sustainability activity** post-intervention household surveys found women had increased their support for fisheries management restrictions more than men. The surveys created an opportunity to capture opinions of men and women of different age groups and within communities involved, despite the cultural treatment of men as the heads of the households. Women had access to family and community-level information, including aquatic resources. Some demographic questions like household sizes, fortnight expenditures, other household occupations, frequency of fish consumption, and reasons why households were consuming less fish were best addressed by women. In Mkwiro, Jimbo, and Vanga communities, women are seaweed farmers, octopus fishers, and processors of sardines. Disaggregated analysis of management preferences and governance principles provided information on women and youth involvement in and contribution to governance issues like decision-making and benefit sharing. Fifty-one percent of the 45 fish biomass trainees in the activity were youth. Active collaboration between the research team and government institutions such as the Fisheries Department, the Kenya Marine and Fisheries Research Institute, and NGOs also empowered women because these organizations are vocal on women's rights and provided opportunities to women, who then became leaders on this issue in their communities. Although opportunities presented to communities were competitive (such as fish landing monitoring), women emerged among the best candidates and were hired.
- The **Zambia Crayfish activity** focus group discussions involved many youth, particularly in Itezhi-tezhi. These were trappers who moved from Kafue Gorge in search of more and larger crayfish. At the same time, the Itezhi-tezhi youth were mostly involved in kapenta fishing and, like women, faced negative impacts from crayfish via damage to gear and catch as they mostly set their nets in shallow waters. They expressed interest in learning about how they could utilize crayfish in different ways.

Human Nutrition

Nutrition was an essential theme within Phase 1 of the Fish Innovation Lab as both a cross-cutting theme and part of the Human Outcomes Area of Inquiry. One particular emphasis was identifying and supporting the most nutritionally vulnerable groups. Globally, evidence points to the first 1,000 days of life (from conception to a child's second birthday) for the highest risk of malnutrition and need for nutrient-dense animal-source foods such as fish. Thus, the Fish Innovation Lab targeted downstream access to fish foods for pregnant and lactating women, infants, and young children. Nutrition data sources (e.g., Demographic and Health Surveys, United Nations Children's Fund Multiple Indicator Cluster Surveys) were recommended to Fish Innovation Lab-funded activities to target the most vulnerable by sociodemographic and economic factors. Small-scale fisher households are among those at high risk and are a sample population across several Fish Innovation Lab activities. Lora Iannotti at Washington University in St. Louis (WUSTL) provided expertise and leadership for the nutrition cross-cutting theme.

Iannotti and her colleague Elizabeth Hahn supported the ME by assisting PIs and other team members to better characterize nutritional problems and fine-tune their targeting and

intervention strategies for reaching vulnerable groups. They worked closely with investigators to build capacity for developing nutrition objectives, nutrition and health assessments or methods (e.g., anthropometry, dietary intakes, nutritional composition of fish, infectious disease morbidities), and survey development. They built capacity around developing proposals for National Institutes of Health and other potential funders supporting nutrition-related work as well as developing manuscripts for nutrition-related journals. Under the Human Outcomes Area of Inquiry, four Fish Innovation Lab activities collaborated closely to share information, methods, and dissemination of effects for nutrition: Samaki Salama in Kenya, FishFirst! in Zambia, Micronutrient Impact of Oysters in Ghana, and Nourishing Nations in Nigeria. All of these activities targeted women and children in the first 1,000 days of life—the most vulnerable period to malnutrition—and were located in very low-resource settings, again heightening the risks for nutrient deficiencies, stunted growth and development. The nutrition team also provided nutrition technical assistance for the Distant Water Fleets buy-in activity research in Madagascar to identify crucial limiting nutrients and child health outcomes that might be alleviated by redirecting fish into local markets.

Under the leadership of the nutrition cross-cutting theme specialist, the Fish Innovation Lab developed course materials for the Nutrition Bait online course including two modules (Introduction to Nutrition and Nutrition Assessment) and two case studies (Kilifi, Kenya and Kebbi, Nigeria). This course will be utilized to describe how fish and other aquatic animal foods can address malnutrition, develop nutrition objectives in research, develop and implement nutrition and behavior change strategies, and identify and apply gold-standard nutrition methods and measures. Dissemination of materials from this course will contribute to local capacity strengthening, informing the designing of nutrition-sensitive programming including fish and other aquatic foods.

In addition to her contributions to publications and communications already indicated in the Capacity Development and Gender Equity and Youth Engagement cross-cutting theme sections above, Dr. Iannotti:

- Received the 2022 Board for International Food and Agricultural Development Award for Scientific Excellence in a Feed the Future Innovation Lab (https://www.usaid.gov/bifad). The award recognizes outstanding research contributions to the interdependent objectives of the U.S. Government's Global Food Security Strategy: inclusive and sustainable agriculture-led economic growth, strengthened resilience among people and systems, and a well-nourished population. The Global Innovator Award recognizes a researcher or research team whose research and outreach through the Feed the Future Innovation Labs demonstrates exemplary scientific merit, relevance to national and/or regional priorities, impact or demonstrated potential for impact, and demonstrated commitment to inclusive development and local capacity development.
- Contributed to a presentation by Gina Kennedy at the 22nd International Union of Nutritional Sciences (IUNS) International Congress of Nutrition session titled, "Dimensions of the Food Environment to Consider When Promoting Fish and Other Aquatic Foods in Low- and Middle-Income Countries."
- Published a manuscript that includes other Fish Innovation Lab coauthors: Iannotti, L. L., Blackmore, I., Cohn, R., Chen, F., Gyimah, E. A., Chapnick, M., Humphries, A. "Aquatic Animal Foods for Nutrition Security and Child Health." *Food and Nutrition Bulletin* 43, no. 2 (2022): 127-147. doi: 10.1177/03795721211061924.
- Presented a seminar to MSU faculty and students titled, "Confronting Hidden Hunger: How Fish Can Fill Health Gaps Around the World."

- Contributed to communication efforts related to nutrition, including the article “More Bites of Fish Recommended in the Dietary Guidelines for Americans 2020-2025.”
- Authored, with two members of her E3 Nutrition Lab and Brietta Oaks, a journal article under review by *Nutrition Research Reviews* entitled, “Mollusk and Crustacean Consumption in the First 1,000 Days: A Systematic Review.”
- Authored a journal article under review by the *Frontiers* research topic on Aquatic Foods: A Solution to Sustainable Diets entitled, “Food Environment Considerations to Promote Aquatic Foods in Healthy Diets.”

Research activity-specific nutrition results include:

- The Nigeria **Aquaculture Diversification in Rural Communities activity** recognized that the contribution of fish to household food and nutrition security depends upon availability, access, and cultural and personal preferences. The activity explored improved access to fish-based sources of nutrition for the poorest and most vulnerable groups through integrated rice-fish farming in Nigeria. The fish/food consumption survey conducted by the activity helped to highlight the linkages between farm diversification strategies and nutrition outcomes. The farmers reported increased availability and access to fish for home consumption due to rice-fish farming. Use of a smoking kiln to add value to fish served the dual purpose of improving access to fish-based food for nutrition and reduced stress/shocks related to fish storage and loss through spoilage, especially where cold storage infrastructure is limited. This process makes fish available for a longer period of time either for home consumption or sales to earn money, thereby enabling purchase of other foods and contributing to dietary diversity.
- The nutrition component of the Kenya **Samaki Salama activity** entailed continuous engagement with participants to improve utilization of fish-based sources of nutrition. Most participants had never received fish nutrition messages, and realization of the expected benefits of consumption motivated them to increase consumption. Caregivers who still had challenges in practicing the messages were offered support to understand and practice them. Cooking demonstrations portrayed fish preparation methods that enable children to get adequate nutrients out of the fish and allowed the mothers/caregivers and their children to share the diversified meal. Seeing their children eat fish enabled mothers/caregivers to demystify the belief that fish had bones that would choke the children, which was the main reason why they fed fish soups only. This was coupled with education messages on hygiene and sanitation during preparation of fish and other foods. Fishers who received gated traps and social marketing took home significantly more fish (12% of catch) than those who did not (7% of catch). The intervention that included the nutrition social marketing campaign significantly increased child growth in height, child fish consumption, and child dietary diversity.
- The **Cambodian Fisheries and Food Processing activity** prepared fish samples for chemical analysis to create a nutritional database. Sensory data on consumer preference of different fish species was collected to determine consumer opinions on the nutritional value of different fish products. Fifty-eight participants thought broth was more nutritious than cooked fish and 7% did not know which was more nutritious, despite cooked fish being the most nutritious. Eighty-eight percent of participants typically cooked fish by boiling in water. This was consistent with many residents believing broth is the most nutritious option. When cooking fish for their family, 72% said they cooked the fish, although many still fed their family broth (56%). Most participants said fermenting fish was the best preservation method at 69%; the second largest response was drying at 18%. These responses illustrated what is common for Cambodian fishermen for

preservation, processing, and household cooking of fish and what consumers believed about where the nutritional value comes from. This, in combination with the nutritional database, allowed the activity to communicate with communities about methods of fish processing, preservation, and cooking to provide the most nutrition, best quality, and flavor of their fish products.

- The Kenya **Coral Reef Fishery Sustainability activity** established the status of fish stocks through the monitoring systems put in place. Results showed stocks were overfished and improved management was needed to make more fish available for household consumption. Fisheries restrictions were rated more favorably by the end of the activity. The nutrition of vulnerable members of the communities was assessed during pre and post-household surveys by asking about the number and types of livelihoods per household, frequency of fish consumption, and factors affecting consumption frequency from fisher and non-fisher community members.
- The **Nourishing Nations activity** in Nigeria worked to strengthen capacity among women and youth fish processors in Delta State to produce high quality, safe, and nutritious processed fish products for local consumption. Activities were designed to improve the quality of fish products rather than access. Key results are detailed under the Gender cross-cutting theme. Analysis of fish nutrient and contaminant profiles and market data informed cost-per-nutrient guides under development to aid in the design of nutrition-sensitive programs and policies.
- The Ghana **Micronutrient Impact of Oysters activity** investigated the contribution of oyster consumption to iron and zinc intakes of women shellfishers in three estuary sites and assessed whether heavy metal contamination of oysters is a health concern. Only 12.5% of the women shellfishers reported consuming any oysters in 24-hour dietary recalls. Approximately 92% of women were identified to have some form of household food insecurity, and severe food insecurity ranged from 72% to 85%. A total of 20% of the women had anemia, and only 21% achieved dietary diversity. Analysis of 915 oyster samples for 17 minerals and heavy metals, including macro-minerals (e.g., calcium, magnesium, phosphorus, potassium, sodium), trace minerals (e.g., chromium, cobalt, copper, iron, manganese, nickel, selenium, and zinc), and heavy metals (e.g., cadmium, mercury, and lead) determined that, compared to eastern oysters in the U.S., oysters in Ghana were much higher in iron (126 mg/kg compared to 46 mg/kg), and the mean HI for arsenic, cadmium, lead, and mercury from oyster consumption among the women shellfishers was low, suggesting no potential health effects of the metals. Promoting oyster consumption may be a promising strategy to increase nutrient intakes and prevent anemia in estuarine communities. The team disseminated the findings to local authorities and shellfishers to help influence the health and nutrition of women shellfishers at the three estuary sites and similar settings.
- The Bangladesh **Harnessing Machine Learning activity** developed a novel methodology to estimate the productivity of key nutrients (protein, energy, calcium, iron, zinc, vitamin A, vitamin B12) from different aquatic farming systems and identify species and crops contributing most to nutrient productivity and economic productivity.
- The Bangladesh **Market Analysis activity** analyzed the National Income Expenditure Survey Data from 2000 to 2016 and revealed that fish consumption increased over the period for every category of household. The lowest income quantile had the fastest growth in fish consumption. The findings indicate that aquaculture is contributing to improving fish consumption patterns irrespective of income groups and the residential status of households.

Resilience of Value Chains and Households

Resilience is a critical component of USAID's work to improve food security and reduce poverty. Resilience refers to the ability of vulnerable groups reliant on income, food, and nutrition from aquaculture and fisheries to mitigate, adapt to, and recover from shocks and stresses. Many practitioners increasingly recognize the fish value chain as a driver of food security and income despite being affected by shocks and stresses.

Aquaculture and fishery systems are particularly vulnerable to extreme storm events, unusual fluctuations in temperature and rain, and anthropogenic stresses and shocks. In aquaculture systems, fish are susceptible to disease outbreak shocks that can cause rapid, high mortalities and move swiftly from farm to farm. As a highly traded commodity, fish are susceptible to price fluctuations and are greatly impacted by feed prices. Contamination of fish from foodborne pathogens can also suddenly close trade markets. These are just some examples of how low ecological, environmental, and economic resilience in aquaculture and fishery systems may have devastating effects for the households and communities that depend on them.

Improving resilience in aquaculture and fisheries relies upon strengthening adaptive capacity and reducing the risks of recurrent crises, shocks, and stresses. The Fish Innovation Lab strengthened the resilience of key aspects of aquaculture and fishery systems in countries including Bangladesh, Kenya, and Nigeria.

Joanna Springer from RTI International provided expertise in resilience for the Fish Innovation Lab and the ME Partners. She developed and launched an online resilience training in early FY22 and reached out to several research teams for follow-up consultations. She developed resilience-focused learning questions addressed during February 2022 learning meetings to allow the activities to apply what they learned during the online training. Springer developed a graphic mapping of seven Fish Innovation Lab activities to USAID's resilience framework to highlight activities with a strong resilience lens (see https://www.fishinnovationlab.msstate.edu/newsroom/2022/06/strengthening-system-resilience-aquaculture-biosecurity-nigeria for an example). Finally, Springer contributed to a blog post on Agrilinks showcasing the Fish Innovation Lab's climate resilience activities in Kenya and Bangladesh and a resilience brief with highlights of program achievements and recommendations.

- Dismukes, A. "Innovations in Aquaculture Production and Fisheries Management Build Climate Resilience." Agrilinks, April 11, 2022, https://agrilinks.org/post/innovations-aquaculture-production-and-fisheries-management-build-climate-resilience.

Research activity achievements related to climate resilience included:

- The Kenya **Coral Reef Fishery Sustainability activity** supported climate adaptation for fishers affected by climate-related pressures in coastal Kenya. The activity improved the livelihoods of fishers in climate refugia, which are safe from adverse climate events due to natural land features. These special protected areas enable fishers to harvest sustainably and profitably, providing a long-term climate-smart and sustainable approach.
- The Kenya **Samaki Salama activity** worked to make current livelihoods more resistant to climate change by modifying a fishing gear to target a climate-resilient fish species (rabbitfish) and reduce the catch of juveniles. Fisher livelihoods can, therefore, be sustained in the face of rising sea temperatures since rabbitfish depend more on seagrasses than coral reefs. Fishers reported increased income from the modified traps, and they are investing this extra income in fishing and other enterprises, increasing their adaptive capacity.

- The Bangladesh **Harnessing Machine Learning activity** employed and promoted use of digital technologies to collect, analyze, and communicate information to address climate change. Example technologies used include machine learning, remote sensing, smartphones, social media, open-source data collection, and video production software. The team combined survey-based research techniques with digital technologies to disseminate knowledge to reach and serve a diverse audience of actors throughout the aquaculture value chain. For example, prawn farmers in southwest Bangladesh face challenges due to climate change. The team produced a video of interviews with farmers who have been impacted, available at https://www.fishinnovationlab.msstate.edu/newsroom/2022/07/negative-impacts-climate-change-prawn-farming.
- The Nigeria **Aquaculture Diversification in Rural Communities activity** contributed to climate mitigation of vulnerable rice farmers in Nigeria by introducing aquaculture to diversify crops. By diversifying rice fields with aquaculture either concurrently or on a rotational basis, rice farmers generated more income from the same amount of land and improved resilience to shock or crop failure. If one crop fails, the technology could be adapted as a form of insurance to ensure the harvest of the complementary crop. Farmers also used water more efficiently, while the aquaculture systems increased the biological diversity of the agro-ecological landscape, minimizing effects of environmental shocks on livelihoods. Aquaculture production also supports climate mitigation by offsetting the greenhouse gases emitted by rice farming.

Research activity achievements related to mitigating risks to production and retail systems included:

- The Nigeria **Improving Biosecurity activity** contributed to resilience at the community, system, national, and regional level by using a cluster management approach that collectively reduced and spread risk to reduce disease exposure. The activity supported and incentivized producers to adopt better fish health management practices and share disease-related information in a transparent and timely way. The team addressed the systemic threat of AMR by encouraging producers to reduce their use of antibiotics. To incentivize behavior changes that benefit the group as a whole— but incur short-term costs for producers— the activity supported locally managed electronic platforms that enabled producers in remote locations to access timely and accurate diagnosis and treatment advice from extension workers. As producers received better and more personalized services, they were more willing to cooperate with reduced antibiotic use guidelines. Finally, government agencies are now able to access a database of real-time and accurate diagnostic information housed by universities, enabling producers and decision-makers to better address new and emerging threats.
- The Zambia **Vaccines for Tilapia activity** developed two autogenous fish vaccines from two killed bacteria identified in sick fish that provided good or some protection using the injection exposure route. The study demonstrated that vaccination against localized disease pressures can be an effective part of an aquatic animal health program for the country to mitigate production risks.
- The Bangladesh **Foodborne Pathogens activity** documented food safety risks in wet markets in Bangladesh with data showing high levels of contamination with foodborne pathogens. The fish cutting board was most frequently contaminated, indicating that an intervention at the cut-up tables in retail markets could reduce pathogen loads in ready-to-deliver fish to consumers.

Research activity achievements related to improving livelihoods for household resilience

included:

- The Nigeria **Lean Production Systems activity** contributed to resilience by improving farm and processing efficiency and thereby improving aquaculture productivity. The activity contributed to resilience on multiple levels by reducing the risk of production loss shocks. Trained coaches learned a process for testing out new practices with a few producers, assessing the results, and then scaling them to a larger number of producers. Skills in iterative development and application of solutions to new and emerging issues are key resilience capacities needed for a dynamic response to threats related to shocks, such as floods. In addition, the practice of peer consultation and greater access to information flows supported by the Lean management approach also improve resilience. Farmers reaped benefits from Lean training, regardless of age, gender, geographical location, company status, farm type, farm size, and annual income based on analysis of 265 projects on 213 fish farms in two states.
- The **Cambodian Fisheries and Food Processing activity** worked with fishers to improve their access to information about current catch levels vis-à-vis sustainable fishing levels due to long-term stresses on fish availability. In addition, the activity supported livelihood diversification by improving processing and preservation techniques to buffer fishers' income despite potential interruptions getting fresh fish to market.
- The **FishFirst! Zambia activity** purposefully designed trainings to have a strong component focused on resilience of value chains and households by training participants on potential income-generating microenterprise opportunities among women and youth entrepreneurs. Trainings focused on producing and marketing dried fish powder and other dried food powders (dried, orange-fleshed sweet potato powder, dried groundnut powder, etc.), and producing and marketing two ComFA+Fish-fortified dishes (cassava balls and nutri-cookies).

Innovation Transfer and Scaling Partnership

Innovation Transfer

As presented in the country summary (Table 3) and in Appendix 2, the Fish Innovation Lab had 58 innovations at different stages of research, field testing, transfer, and uptake by the end of Phase 1. This included nine technologies in plant and animal improvement research, 33 in production systems research, and 16 in social science research. Overall, 17 technologies were in Phase 1: Under Research, 14 were in Phase 2: Under Field Testing, 19 were in Phase 3: Made Available for Transfer, and eight were in Phase 4: Demonstrated Uptake by the Public and/or Private Sector.

Plant and Animal Improvement Research

Innovations in **Phase 1: Under Research** included:

- Improvement of Seeds and Broods of Experimental Fish (Cryogenic Sperm Banking): Seeds of three IMCs and exotic carps were produced using cryopreserved sperm in government and private hatcheries for improving their quality. Sperm of two river-origin IMCs and three newly imported exotic carps by DoF were cryopreserved, and a cryogenic sperm bank was developed. It is expected that the quality of seeds of both IMCs and exotic carps produced by cryopreserved sperm will be improved, and the hatchery operators will be able to produce good quality broods. The growth of seeds obtained from the quality broods is expected to be faster and benefit farmers.

- Sensory Evaluation of Fish Product Training (Cambodian Fisheries and Food Processing): This training video was designed to educate personnel in Cambodia on sensory evaluation techniques for fish products. Sensory evaluation is a critical method for assessing the quality attributes of food products and determining consumer acceptance. Given that consumer acceptance is essential for marketability, this video aimed to equip individuals with the necessary knowledge for product research and development in the fish products sector.
- Genetically Improved (Generation 1) Catla Families (Carp Genetic Improvement): A total of 201 catla families were established, with 120 families in 2021 and an additional 81 in 2022. These families belonged to Generation 1 and were reared separately for tagging and progeny testing. There were 160 positively selected families (comprising 89 from 2021 and 71 from 2022), which exhibited rapid growth characteristics, and 15 negatively selected families were included in 2021, reserved for future genomic research. There were 26 control line families (16 from 2021 and 10 from 2022) serving as a reference for potential performance trials involving the positively selected families.
- Genetically Improved (Generation 2) Silver Carp Families (Carp Genetic Improvement): In 2022, 240 Generation 2 silver carp families (one species) were made and separately nursed for tagging and progeny testing. These were comprised of 192 positively selected families (i.e., rapidly growing), 16 negatively selected families (for future genomic research), and 32 control line families as a reference point for future performance trials of the positively selected families.

Innovations **in Phase 2: Field Testing** included:

- Production of Quality Fish Seeds and Broods Using Cryopreserved Sperm (Cryogenic Sperm Banking): Government and private hatcheries produced seeds of three IMCs and exotic carps using cryopreserved sperm to enhance their quality. This process utilized cryopreserved sperm from IMCs originating from the Halda and Padma rivers, along with sperm from three exotic carp species recently imported from China by the DoF. The initiative aimed to improve the quality of seeds for both indigenous and exotic carps, enabling hatchery operators to produce superior broods. The anticipated outcome is faster-growing seeds, which will ultimately benefit farmers through improved yields.
- Tilapia Vaccine for Small Scale farmers (Vaccines for Tilapia): The activity worked on the development of a fish vaccine. A trial vaccine was successfully formulated and, as of the end of activity, was progressing through laboratory and field trials. This technology was specifically designed for small-scale producers who are grappling with significant mortalities caused by identified bacterial diseases. The innovation aims to provide an effective means of disease management, reducing reliance on antibiotics. Ultimately, this approach aligns with the long-term goal of achieving environmental sustainability.

Innovations in **Phase 3: Ready for Uptake** included:

- Genetically Improved (G3) Rohu Families (Carp Genetic Improvement): A total of 215 G3 rohu families were established. These families were reared separately for tagging and progeny testing. Among them, there were 166 positively selected families characterized by rapid growth, 15 negatively selected and reserved for future genomic research, and 34 control line families included as a reference point for potential performance trials involving the positively selected families.

Innovations in **Phase 4: Demonstrated Uptake by the Public and/or Private Sector** included

- Fish Feed Development (Aquaculture Diversification in Rural Communities): UI partners, with assistance from the University of Georgia, obtained access to feed development software to develop low-cost, high-quality fish feed utilizing locally available ingredients. This tool provided nutritional information on key local feedstuffs and their optimal combinations. The primary objective was to create an innovative template for using locally sourced feed ingredients in mini feed mills, which are essential for the productivity of small- and medium-scale aquaculture operators in the region.
- Locally Adoptable Fish-Seed Production Techniques for African Catfish and Tilapia (Aquaculture Diversification in Rural Communities): The team developed hatching structures for fish-seed production made from locally available materials, such as hapas and fiberglass. Implementing this innovation addresses knowledge gaps and limited availability of fish seed in Kebbi and Ebonyi States and could create substantial employment opportunities, particularly for youth and women, in hatchery operation and seed development. It could also ensure the availability of quality fish seed to farmers, thereby enhancing yield, promoting food security, and increasing income.

Production Systems Research

Innovations in **Phase 1: Under Research** included:

- National Aquatic Animal Health Strategy – Outline and Action Plan for Nigeria (Improving Biosecurity): A consortium comprising various stakeholders in Nigeria's aquaculture sector, including fish farmers, private veterinarians, government officials, private organizations, and members of relevant associations, convened to develop an outline for a National Aquatic Animal Health Strategy. The data-gathering method employed was a Focus Group Discussion, involving up to 30 stakeholders. This discussion was structured around a self-assessment template, a tool developed by FAO and the World Organization for Animal Health, which included key components for assessment and their respective statuses.
- Development of Process Maps to Inform Training, Development, and Technology Deployment (Cryogenic Sperm Banking): Process maps were developed for germplasm repository creation and for the utilization and distribution of the germplasm, which included training for end users. These process maps were designed to improve the overall planning, development, application, and training processes associated with the collection, preservation, documentation, use, and monitoring of cryopreservation and repository development technologies.
- Development of Training Curriculum for Intensive Training and Practice (Cryogenic Sperm Banking): A training curriculum focusing on the needs and tools essential for repository development was prepared. This curriculum was designed for delivery through a series of workshops, which encompassed both theoretical and practical aspects. Additionally, these workshops featured demonstrations of both commercial and open-source equipment and devices.
- Feed Formulation for Bighead Catfish Culture in Recirculation Aquaculture System (Bighead Catfish): An approach to assess the performance of BC using locally available feeds from the market, each with varying protein levels, was developed. For detailed findings and analysis, please refer to the Experimental Report on Commercial Aquafeed Evaluation for Bighead Catfish Culture in Recirculation Aquaculture System.
- Improved Crayfish Trapping System for Zambia (Zambia Crayfish): In certain areas, crayfish traps are traditionally crafted from locally sourced reeds, bound together with fibers obtained from riverbank reeds. With the help of a colleague at UNZA, the team

procured crayfish traps akin to the Australian-style designs for conducting fishing trials in Zambia. These traps closely resembled the standard trap recommended for assessing crayfish populations in Zimbabwe. The primary areas of research focused on evaluating the catchability of crayfish using such gear in Zambian waters and assessing their cost-effectiveness.

Innovations **in Phase 2: Field Testing** included:

- Small-Scale Black Soldier Fly Production (Aquaculture Diversification in Rural Communities): The activity pioneered a low-cost, nutrient-rich fish feed production method utilizing BSFL. This innovative approach focused on developing a replicable model for using black soldier flies as a sustainable feed source in integrated aquaculture systems. The technology behind this fish feed production was designed for easy adaptation and scalability. Furthermore, the implementation of this method is expected to generate employment opportunities, particularly among young people and women, thereby contributing to community development and economic empowerment.
- General Guidelines on Better Management Practices for Fish Production Systems in Delta and Ogun States, Nigeria (Improving Biosecurity): This manual offered general guidelines aimed at establishing or enhancing biosecurity practices in Nigerian aquaculture farms. Serving as a foundational document, it assisted in the planning of future aquaculture management programs and the development of Standard Operating Procedures (SOPs). These guidelines were designed for implementation by existing aquaculture farms in Nigeria to promote sustainable and environmentally responsible farming practices. These BMP guidelines were generalized and adaptable across various production systems.
- Fisher Gear Modification (Samaki Salama): Locally fabricated fishing traps were modified to include an escape gap, aimed at reducing the capture of immature fish. This modification is expected to enhance harvest efficiency and contribute to the sustainability of fish populations.
- Fisheries Harvest and Recovery Monitoring Protocol (Cambodian Fisheries and Food Processing): A protocol was established to document, visualize, and analyze data from artisanal fisheries, covering aspects such as species diversity, abundance, size distributions, fishing locations, and yield per effort. This protocol was implemented by local villagers, actively involving them in fisheries data collection and analysis. This participatory method was designed to facilitate the successful transfer of the program to the local Community Fisheries Council upon activity completion.
- Sre Ambel River Fishery Community Fisheries Assessment Tool: iFISH App (Cambodian Fisheries and Food Processing): An application developed in R Shiny for data analysis and visualization of the Sre Ambel River fisheries was created, featuring four main pages: capture per unit effort, length-frequency, species composition, and spatial characteristics, including mapping of fishing areas and travel distances. Each page is equipped with tabs allowing users to select specific species, fishing gear, village, and season. Additionally, a training video was produced to assist end users, such as fisher community leaders, government fisheries agencies, NGOs, and graduate students, in effectively utilizing the app.
- Application of Lean Management in Aquaculture (Lean Production Systems): Training on the application of Lean management in aquaculture was conducted for local producer associations and educational institutions. The program ensured inclusive participation, with both male and female trainees, and included a focus on engaging youths.

- Red Cap (Lean Production Systems): A database was established to support management decisions based on Lean principles in aquaculture. Farmers input data using a smartphone app, ensuring ease of access and real-time data collection. This initiative benefits a diverse group of stakeholders, including men, women, and youth. The application of Lean Production Technology is anticipated to reduce waste and enhance farm productivity, ultimately leading to increased profits and improved incomes.
- Atlan Collect Application (Coral Reef Fishery Sustainability): The mobile application, installed on smartphones, was utilized by trained community data collectors and county fisheries officers for monitoring fish landings at the grassroots level. It facilitates the recording of fish weights across various groups and fishing efforts, enabling comparisons between data collated by the community and that gathered by trained government officers. This comparison informs assessments of reef status and community capacity and aids in making recommendations to relevant authorities. Additionally, the application serves to raise awareness, expose, and enhance community knowledge regarding the status of fisheries.

Innovations in **Phase 3: Ready for Uptake** included:

- SOPs on Fish Sampling Techniques for Disease Diagnostics (Improving Biosecurity): SOPs for fish sampling techniques, essential for disease diagnostics, were developed. These SOPs encompass a comprehensive range of procedures including the identification of clinical signs, examination of fresh fish, bacteriology sampling, histopathology sampling, and molecular diagnostic sampling. This structured approach ensures accuracy and consistency in disease diagnosis, contributing to effective fish health management.
- E-Learning Resources Learn.ink Course 1: Fish epidemiology and health economics course using Open Data Kit, Learn.ink Course 2: Fish Sampling Microlearning Curriculum, and Learn.ink Course 3: Syndromic Surveillance Course (Improving Biosecurity): The data collection tool was complemented by online course modules hosted on the Learn.ink platform, facilitating remote training for national partners. This included university researchers, enumerators, aquaculture extension workers, and field officers from both government and NGOs. The package also included a detailed guide for conducting epidemiological surveys with aquaculture producers. This comprehensive training approach was designed to promote extensive utilization of the fish epidemiology and health economics tool, enabling the collection of large data sets across diverse farming systems and geographical areas.
- Insects as Fishmeal Replacement (Farming Insects in Nigeria): BSF farming presents a promising avenue for boosting the productivity of small-scale aquaculture value chains in Nigeria. However, critical parameters like optimal feed ratios, cost-effectiveness, appropriate waste streams, and the integration of BSF within aquaculture production have yet to be field-tested with small-scale producers. To address this, the activity engaged resource-poor farmers, including women and youth, by establishing a co-creative partnership with local producers. This initiative aimed to develop small-scale, backyard BSF and fish farms, supporting both subsistence needs and income-generation activities.
- Smoking Tunnel for Fish (Cambodian Fisheries and Food Processing): Development of an affordable and sustainable smoking tunnel for fish was initiated, aimed at enhancing the quality and market value of fish products. This project is being privately implemented by local fishermen, representing a significant step towards improving fish processing techniques in the community.

- Sample Preparation Techniques for Fish Nutrient Analysis (Cambodian Fisheries and Food Processing): Sample preparation involving liquid nitrogen grinding was employed to preserve nutrients for chemical analysis. This technique ensured the integrity of the samples, providing accurate and reliable data for nutritional assessments.

Innovations in **Phase 4: Demonstrated Uptake by the Public and/or Private Sector** included:

- Rice-Fish Farming (Aquaculture Diversification in Rural Communities): The strategy involves effectively integrating fish farming into rice fields, thereby optimizing the use of existing resources such as land and water. This approach shifts from producing a single crop (rice) to dual production (rice and fish). The emphasis was on the adoption of this technology by rice farmers and other potential producers or investors. Key benefits include the efficient utilization of limited water and land resources, a reduced dependency on agrochemicals compared to traditional rice cultivation, increased employment opportunities, income diversification, and enhanced local food and nutrition security.
- Value Addition – Fish Processing (Aquaculture Diversification in Rural Communities): Enhancement of the value of fish harvested via the integrated rice-fish system was achieved through the implementation of fish smoking techniques. This approach is designed to extend the shelf-life of fresh fish, thereby reducing food loss and augmenting income margins. Additionally, it ensures the availability of fish for consumption throughout the year. This initiative also contributes to the creation of additional employment opportunities within the fish value chain, supporting local economies and promoting sustainable livelihoods.
- Water Management in Integrated Rice-Fish System (Aquaculture Diversification in Rural Communities): Effective water management strategies were implemented within the rice-fish system to ensure the optimal growth of both rice and fish. These strategies were designed to create a balanced ecosystem that supports the health and productivity of the rice crops while providing a conducive environment for fish cultivation. This integrated approach not only maximizes resource efficiency but also contributes to sustainable agricultural practices.
- Using Vinegar as an Inexpensive Fish Preservation Technique Without Cold Chain (Cambodian Fisheries and Food Processing): Research and application of buffered vinegar and vinegar for preserving fresh fish without refrigeration were successful. The sensory attributes of the preserved fish were found to be acceptable. This innovation addresses the challenge of the absence of a cold chain by utilizing natural antimicrobial solutions, similar to those widely used in the meat and poultry industries.
- Kobo ToolBox Application (Coral Reef Fishery Sustainability): The Kobo Collect App, installed on mobile phones, was employed by trained community data collectors and county fisheries officers for monitoring fish landings, especially after the discontinuation of Atlan Collect. This app records fish weights across different groups and fishing efforts, facilitating a comparison between data gathered by the community and that by trained government officers. Such comparisons are crucial for assessing the status of the reef, evaluating community capacity, and providing recommendations to relevant authorities. Additionally, the app plays a significant role in raising awareness, increasing exposure, and enhancing community knowledge about fisheries status. It is designed for both online and offline use, ensuring accessibility under various conditions.

Social Science Research

Innovations in **Phase 1: Under Research** included:

- Lean Management Tools (Lean Production Systems): Participants in the Nigerian aquaculture value chain, focusing on catfish and tilapia production, were trained to identify inefficiencies, reduce postharvest losses, enhance waste management, and lower production costs using Lean management tools. These tools were specifically designed to help actors in the value chain recognize and address waste, inefficiencies, and malpractice in their operations. Through this training, participants were equipped to modify their practices, thereby improving productivity by effectively identifying waste streams in the aquaculture value chain.
- Training Course for Fish Processors on Nutrition and Food Safety and Fish Processing/Handling (Nourishing Nations): The activity developed a training program for fish processors, comprising seven modules designed for individuals with low literacy levels. The course covered essential topics in nutrition and food safety and included a comprehensive facilitator's guide to aid in effective teaching.
- Cost-per-Nutrient Guide of Select Fish Products and Other Animal Source Foods (Nourishing Nations): A cost-per-nutrient guide was developed to evaluate the nutrient value of processed fish products relative to other animal source foods in Nigeria. This guide will facilitate an informed analysis of the country's food environment. The nutritional profiling of these fish products is expected to assist government actors in crafting more nutrition-sensitive programs and policies. Indirectly, the data generated from this activity could contribute to updating the National Food Composition Table and inform the development of nutrition education content and messaging based on Food Based Dietary Guidelines.
- Export Competitiveness Policy Approach (Market Analysis): This policy approach focused on assessing the competitiveness of shrimp exports in Bangladesh, China, India, Indonesia, Thailand, and Vietnam. The study examined various factors influencing Bangladesh's shrimp export competitiveness, taking into account macroeconomic and policy variables. The analysis utilized the Revealed Symmetric Comparative Advantage index method to quantify export competitiveness and employed a dynamic autoregressive distributed lag simulation model to identify the driving factors behind shrimp competitiveness.
- Adoption Strategies in COVID-19 Policy Approach (Market Analysis): This policy approach aimed to generate information to inform the development of action plans for addressing future challenges similar to the COVID-19 pandemic, both at the operational and policy levels. Within this framework, the activity assessed the impact of COVID-19-related preventive measures and their subsequent effects on the aquaculture and fisheries sectors in Bangladesh, considering the perspectives of all stakeholders. This analysis was based on primary data collected from Bangladesh as an empirical case study, and it also evaluated the adaptation strategies employed to mitigate the effects of the COVID-19 pandemic.
- Trade Credit in Fish Farming (Market Analysis): This policy approach aimed to empirically assess whether trade credits contribute positively or negatively to the aquaculture sector in Bangladesh. It also sought to understand the factors influencing farmers' decisions to enter into trade credit contracts, utilizing farm-level economic data. The analysis employed the Meta Frontier Data Envelopment Approach to quantify the impact of trade credits at the farm level, as well as the Propensity Score Model and Probit regression to identify statistically significant factors influencing trade credit decisions.

- Intra Household Fish Consumption Pattern in Bangladesh (Market Analysis): Analysis of National Income Expenditure Data from 2006 to 2016 revealed that fish consumption has shown a consistent increase across various categories of households, including rural, urban, and income quantiles. Notably, the lowest income quantile, representing the poorest households, has witnessed the most rapid growth in fish consumption. Within this trend, there is a notable preference among the lowest income quantile for low-value cultured fish species. In contrast, high-value cultured fishes are primarily consumed by households in the upper income quantile. Furthermore, a significant portion of the fish consumption expenditure among the lowest quantile households is allocated to low-value capture-based small indigenous species and culture-based catfish.
- Qualtrics Platform for Zambia Crayfish Impacts Survey (Zambia Crayfish): A survey on crayfisheries practices and basic postharvest utilization was initially prepared on paper by the research team. Some of the survey questions were field-tested through in-person interviews with crayfishers in Siavonga, Zambia. Recognizing the potential benefits of a web-enabled version, the team decided to create one. This digital format would offer convenience for certain survey informants, including local government officials, national agency personnel, and commercial entities, who may find it useful.
- Fishery Length-Frequency Analysis/Stock Assessment (Zambia Crayfish): Length-frequency analysis is a widely recognized method employed by fisheries scientists to evaluate the status of fishery stocks. A notable sign of potential overfishing is a shift towards smaller predominant fish size classes. In the context of invasive species like crayfish in Zambia, the deliberate overfishing of invasive stocks may be considered as a management or control strategy. This approach was presented to officials from the Zambia Departments of Fisheries and Environmental Protection during a workshop held on March 17, 2023, at UNZA.

Innovations **in Phase 2: Field Testing** included:

- Nutrition Social Marketing (Samaki Salama): The nutrition social marketing campaign encompassed a diverse array of communication channels, including home visits, workshops, posters, calendars, banners, radio broadcasts, t-shirts, stickers, flyers, cooking classes, and community gatherings. The campaign's key messages were tailored for a broad audience, including mothers, fathers, grandmothers, community health workers, and other key stakeholders.
- Training Course for Fish Processors on Nutrition and Food Safety and Fish Processing/Handling (Nourishing Nations): Training materials were developed for fish processors, focusing on nutrition to enhance their capability in marketing fish-based products, especially to consumers such as women with young children. This initiative aimed to equip processors with the knowledge to effectively communicate the nutritional benefits of fish products, thereby supporting healthier dietary choices.
- Complementary Food for Africa+Dried Fish Powder (ComFA+Fish) (FishFirst! Zambia): The ComFA+Fish technology utilizes locally sourced, nutrient-dense small pelagic fish, primarily in dried fish powder form, combined with other local nutrient-rich ingredients to enhance the nutritional value of traditional staple foods. This technology is driven by three primary objectives: 1) sustainably changing nutrition behaviors, 2) increasing the resilience of value chains and households, and 3) enhancing capacity building.
- Validated ComFA+Fish Recipes for ComFA+Fish Recipe Booklets (English and Tonga versions) (FishFirst! Zambia): Six validated recipes suitable for consumption by 6–23-month-olds and households were developed, resulting in the creation of two

ComFA+Fish Recipe Booklets in English and Tonga versions. These recipes included: 1) ComFA+Fish Complementary Maize Porridge; 2) ComFA+Fish Chibwabwa Fisashi; 3) ComFA+Fish Kapenta Chutney; 4) ComFA+Fish Bean-Vegetable Soup; 5) ComFA+Fish Cassava Bites; and 6) ComFA+Fish Nutri-Biscuits. Notably, Recipes 5 and 6 were also promoted for microenterprises and income generation by enabling the production and sale of ComFA+Fish-fortified foods in local markets.

Innovations in **Phase 3: Ready for Uptake** included:

- Fish Epidemiology and Health Economics Survey Tool (Improving Biosecurity): The activity implemented an innovative online data collection tool, specifically designed for Android mobile devices, to facilitate comprehensive farmer surveys. This tool is crucial in generating vital data on fish epidemiology and health economics. The primary objective of data collection is to address the existing gap in baseline data regarding production systems and management, which is essential for effective surveillance and informing targeted interventions in aquatic food systems. The type of data collected encompasses a wide range of parameters including farm characteristics, labor details, pond preparation techniques, inputs, treatments, stocking information, and records of baseline or abnormal mortality rates. This data is gathered using the Open Data Kit Collect mobile application, a user-friendly and efficient platform for field data collection.
- Data Visualization Tools for Fishpond Identification (Harnessing Machine Learning): The activity introduced an interactive online data visualization tool that integrated data from remotely sensed images of southwest Bangladesh with survey results. This tool aims to estimate the multi-dimensional contributions of aquaculture to the economy and nutrition, focusing on aspects such as production, economic value-added, and employment, with a particular emphasis on gender differentiation and value chain segments. Developed based on stakeholder consultations, this publicly accessible web-based tool enables users to interact with and visualize the generated data effectively.
- Extension video trainings (Harnessing Machine Learning): The activity launched dedicated YouTube and Facebook channels in the Bangla language. These platforms featured short videos where innovative individuals shared their practices in their own words. The aim was to disseminate these insights widely through social media to enhance capacity building and accelerate the adoption of new technologies and improved practices among farmers and other value chain actors. To augment these efforts, existing social media channels already popular within the aquaculture sector, such as public fish farmers groups on Facebook, were leveraged.

Innovations in **Phase 4: Demonstrated Uptake by the Public and/or Private Sector** included:

- Low-Literacy Tools to Help Women and Youth Fish Processors Better Market their Products (Nourishing Nations): Tools designed for low-literacy audiences, such as wristbands and hand fans, were developed and distributed to women and youth involved in fish processing. These tools were imprinted with messages highlighting the nutritional and health benefits of fish. The aim is to educate consumers and the general public about these benefits, assisting processors in effectively marketing their fish products. This initiative also serves to enhance the business and marketing skills of these processors.

Scaling Partnerships

In FY23, the Fish Innovation Lab's research portfolio included 18 activities that developed 58 innovations. The Fish Innovation Lab coordinated with the Feed the Future Nigeria Agricultural

Extension and Advisory Services activity to plan aquaculture technology scaling, participated in Feed the Future's Innovation to Impact activity to scale complimentary foods with fish powder, and collaborated with private fish hatcheries, aquaculture producer cooperatives, feed mills, fish processors, and food producers in Nigeria, Bangladesh, and Zambia to scale technologies.

Environmental Management and Mitigation Plan

The Fish Innovation Lab Environmental Management and Mitigation Plan (EMMP) was originally approved by the Bureau of Resilience and Food Security environmental officer on July 8, 2019. After completing the competitive awards process and commissioning the final awards, the Fish Innovation Lab supported USAID in revising the Initial Environmental Examination (IEE). The team also revised the EMMP, which included addition of climate risk screening and management. Both documents were submitted and approved in FY21.

Environmental Management and Mitigation Reports are presented in Appendix 4, and Climate Risk Screening and Management Reports are presented in Appendix 5.

Open Data Management Plan

The Fish Innovation Lab ME worked with all research teams to explain, advise, and support the data management plan. All teams submitted their data upon completion of data collection, analysis, and publication of results on the designated Fish Innovation Lab Harvard Dataverse. A summary of research databases is available in Appendix 6. Teams used Piestar as the Fish Innovation Lab's data management platform for information management, monitoring, data visualization, and routine reporting, including updates to the USAID Development Experience Clearinghouse, Development Data Library, and Harvard Dataverse.

Management Entity and Management Entity Partner Activities

The Fish Innovation Lab ME implemented its research portfolio to achieve knowledge and technology adoption, scaling, and impact. The Fish Innovation Lab launched five Quick Start activities in FY19. In April 2019, the Fish Innovation Lab released a competitive request for applications. After screening and reviewing the 243 concept notes received, the Fish Innovation Lab invited 41 teams to submit full proposals. Thirteen research-for-development activities were awarded in FY20, and six direct commissioned studies and a buy-in were awarded in FY21. This section describes the activities the ME implemented to support Phase 1 research activities. In FY23, the ME developed and implemented a closeout system to ensure all the research activities funded during Phase 1 of implementation closed and met programmatic, financial, and administrative requirements by USAID and MSU.

Support the Fish Innovation Lab Research-for-Development Activities

During the 5-year Phase I, the Fish Innovation Lab ME and its partners provided technical assistance to the funded research-for-development activities through the regional coordinators and specialists as well as the cross-cutting theme specialists. The ME conducted virtual trainings on finance and administration, communications, and monitoring, evaluation, and learning for the new grantees. Upon request, the cross-cutting theme and country specialists reviewed and provided feedback on research protocols, survey tools, and the development of capacity-building strategies. The ME also supported the sharing of lessons learned via blogs,

success stories, and joint conference and workshop panels.

The country coordinators and specialists met regularly with in-country partners and provided technical support to activity implementation.

The Fish Innovation Lab ME maintained communication with the ME Partners via monthly virtual ME Partner meetings. These meetings included a mix of activity administration and technical updates, and they provided a forum for quick updates and sharing of lessons learned. When deemed necessary, the ME also conducted individual virtual meetings with PIs as needed to brainstorm and problem solve. The ME, in coordination with the AOR, organized meetings with five USAID missions (Bangladesh, Ghana, Nigeria, Kenya, Zambia, and Cambodia), including the dissemination of findings and accomplishments. An in-person annual meeting was conducted in 2023. Virtual annual meetings were conducted in 2020, 2021, and 2022. Annual meetings included the Fish Innovation Lab ME, ME Partners, EAB, AOR, and activity PIs.

Implement Knowledge Management Plan

The Fish Innovation Lab ME implemented several internal and external communications activities to 1) continue building awareness of the lab and its research results and 2) facilitate internal communication among new and existing stakeholders to drive learning and networking (see Communications section below for full details).

Monitoring, Evaluating, and Learning from Research Findings

The Fish Innovation Lab ME ensured accountability for implementation of the Fish Innovation Lab research portfolio using the Fish Innovation Lab monitoring, evaluation, and learning (MEL) plan, which was approved in March 2019. RTI International coordinated Fish Innovation Lab MEL activities described below.

Indicators: The team submitted a revised MEL plan to USAID. This included targets for the six activities that began mid-FY21. USAID approved the revised MEL plan, including updated performance indicator reference sheets and target descriptions for each subaward. The MEL advisor supported the teams on indicator submissions and supported the ME in the review, validation, and preparation of data for reporting.

Learning agenda: The Fish Innovation Lab implemented a learning agenda for Phase 1 that had four primary purposes: 1) Facilitate sharing of best practices and findings related to cross-cutting themes and other questions prioritized by activities; 2) Promote best research for development practices, particularly related to gender and youth inclusion, capacity development, resilience, and nutrition outcomes; 3) Provide a structure for sustained engagement between teams to promote collaboration; and 4) Harvest and communicate lessons learned related to research for development best practices.

As part of USAID's Collaborating, Learning, and Adapting approach, a set of learning agenda questions were developed with research teams to test and explore assumptions and hypotheses linked to the Fish Innovation Lab Theory of Change throughout implementation. The Fish Innovation Lab's learning agenda covered five themes over 5 years. Over the course of Phase 1, the MEL advisor conducted a series of learning meetings (February 2021, July 2021, February 2022, July 2022, and May 2023) to address the learning agenda questions developed under each learning theme.

In FY23, the Fish Innovation Lab assessed the effectiveness of all learning agenda events, finding that the events played a key role in shaping the direction and outcomes of the research activities. The events provided a valuable platform for participants to share experiences, challenges, adaptation strategies, and successes, fostering a culture of collaboration and

knowledge sharing among the research activities. The learning events contributed to the collective efforts of Fish Innovation Lab research activities in addressing challenges and achieving their objectives. The following summarizes content by theme in the 5 years of implementation:

1. **COVID-19**: Highlighting the impact of COVID-19 on the fish value chain and the need for adaptive strategies to mitigate its effects, research teams shared experiences and challenges of navigating disruptions in supply chains, market closures, and reduced access to resources. Teams adapted by leveraging local expertise and building local partnerships.
2. **Women and Youth Engagement**: Emphasizing the importance of engaging women and youth in fish value chains, participants shared experiences in promoting women and youth entrepreneurship and women's empowerment, enhancing women's access to resources and opportunities, and addressing gender-based barriers to participation in the fish value chain. Strategies included targeted training, capacity-building, and empowerment initiatives.
3. **Public- and Private-Sector Stakeholder Engagement**: Providing a platform for participants to share experiences in engaging with public- and private-sector stakeholders, participants discussed challenges and opportunities in building partnerships, enhancing stakeholder buy-in, and fostering a culture of collaboration among different actors in the fish value chain.
4. **Innovation/Technology Adoption and Scaling with a Resilience Lens**: Highlighting the importance of promoting the adoption of innovative technologies in the fish value chain, participants shared experiences in scaling technologies, enhancing access to information and training, and fostering a culture of innovation among fish farmers and fishers. Events also emphasized the need for building resilience in communities and enhancing the adaptive capacity of fish farmers and fishers.
5. **Health and Nutrition**: Emphasizing the importance of integrating nutrition-sensitive approaches into research activities from the beginning, participants shared experiences in promoting nutritious fish-based diets, addressing micronutrient deficiencies, and improving the nutritional status of vulnerable populations. Strategies included engaging with local communities, using research methods to gather information, and the need for collaborations with local authorities to address the challenges of measuring long-term impacts of nutrition interventions.

Conduct a Self-Assessment

The ME commissioned a self-assessment of Fish Innovation Lab activities and ME performance. Data collection and analysis took place during the third and fourth quarter of FY22. The self-assessment report was used to improve ME operations and provide insights for strategic development of future research and capacity development activities in Phase 2. The final version of the self-assessment document was shared with USAID's AOR in January 2023.

Management Entity – MSU

The ME led the Fish Innovation Lab ME Partners and supported research-for-development activities in a comprehensive manner. Summarized activities of each member are highlighted below.

Mark Lawrence provided direction and oversight for all Fish Innovation Lab activities. Lawrence coordinated the Fish Innovation Lab ME and ME Partners. He served as the primary contact for

the Fish Innovation Lab AOR and represented the Fish Innovation Lab at meetings and activities. Lawrence facilitated collaboration with current and potential research partners. Examples include meeting with faculty from the University of Nairobi who implement Animal Health Innovation Lab activities to explore alternatives for future collaborations; facilitating interactions between the Feed the Future Nigeria Agricultural Extension and Advisory Services activity and Fish Innovation Lab teams in Nigeria; engaging in discussions to explore collaborations between the Fish Innovation Lab and Farmer-to-Farmer program in Africa, which resulted in volunteer assignments for Fish Innovation Lab Nutrition Specialist Lora Iannotti in Madagascar and PI Terezie Tolar-Peterson in Zambia.

Lawrence also represented the Fish Innovation Lab at numerous events, including:

- Innovation to Impact Online Learning event
- A Public Consultation on the Board for International Food and Agricultural Development's Plans to Propose a Subcommittee on Minority Serving Institution Engagement and Leadership in USAID's Agricultural, Food Security, and Nutrition Programming
- Presentation on “Feed the Future Innovation Lab for Fish: A Five-Year Reflection” to the Bureau for Resilience and Food Security Research Community of Practice

Lawrence also serves on the Technical Working Group for the FAO Progressive Management Pathway for Improving Aquaculture Biosecurity. He participated in Technical Working Group meetings.

Stephen Reichley served as Risk Mitigation Specialist (October 2020-present) and Deputy Director (September 2022-present). In these roles, Reichley provided support for the management and implementation of the Fish Innovation Lab and served as Lawrence’s delegate and alternate point of contact for USAID. He attended Fish Innovation Lab virtual meetings and often served as a moderator. This included participating and moderating learning meetings for the Asia aquaculture, Africa aquaculture, and fisheries groups. Reichley facilitated the maintenance of the Fish Innovation Lab Aquaculture and Fisheries Resource Center on the website. He supported document formation and review for reports, plans, etc. Reichley represented the Fish Innovation Lab at numerous meetings and conferences including Innovation Lab Directors’ and Regional Partners meetings as well as meetings with USAID Missions in partnering countries. He presented to various groups to raise awareness and identify opportunities for potential collaborations.

Peter Allen represented and promoted the Fish Innovation Lab at national and international conferences, gave presentations, networked, attended Fish Innovation Lab-sponsored presentations, and participated and served as a moderator for Fish Innovation Lab PI reporting sessions and annual meetings. Allen organized and led the Aquaculture America Conference’s Fish Innovation Lab session entitled, “Fish to Feed the World: Advancing Sustainable Solutions for Global Food Security.”

Jared Dees worked with all awarded activities to ensure financial compliance with USAID and MSU rules and regulations and coordinated subaward management with the MSU Office of Sponsored Projects. Dees also managed all subawards issued to ME Partners, and he supported Fish Innovation Lab virtual meetings. Dees moved to a different position at MSU in May 2023.

Alaina Dismukes supported Fish Innovation Lab communications with a focus on activity-level communications (see Communications section below).

Shauncey Hill assisted the director, deputy director, and ME Partners in planning, organizing,

and managing Fish Innovation Lab activities. She ensured compliance with USAID and MSU rules and regulations, and she coordinated programmatic support for the activities. Hill moved to a different position at MSU in April 2023.

Kathleen Ragsdale and **Mary Read-Wahidi** supported the Fish Innovation Lab as the Gender and Youth Equity specialists. They participated in the USAID Zambia Mission meeting and led and contributed to more than 40 gender and youth-related activities, with a focus on high-impact and open-access resources as well as collaborations with cross-cutting theme leads and across Innovation Labs. They also administered the GRADA-FIL Wave I and II surveys. More detail is provided in the Gender Equity and Youth Engagement cross-cutting theme section above.

Gina Rico Mendez first engaged with the Fish Innovation Lab in FY22 leading the preparation of the internal self-assessment. In January 2023, she moved into the roles of Human Outcomes specialist and MEL specialist, providing programmatic and technical support in the implementation of the research program as it reached its final year of Phase 1 implementation.

Laura Zseleczky managed internal and external communications for the Fish Innovation Lab (see Communications section below).

ME Partner – RTI International

RTI International supported the Fish Innovation Lab team in MEL (Rebecca Jeudin) as well as resilience (Joanna Springer). Jeudin revised the MEL Plan and designed, organized, and conducted learning agenda events. Springer developed and launched the online resilience training and worked with research teams on resilience frameworks and activities.

ME Partner – TSU

Madan Dey served as the Asia specialist. He coordinated various activities for the Fish Innovation Lab in Bangladesh and Cambodia and collaborated with the Asia regional coordinator, M. Gulam Hussain. He successfully organized the Bangladesh Aquaculture Sector Meeting from July 24–28, 2022. A total of 220 national and international participants, including dozens of stakeholders, local fish farmers, and entrepreneurs, joined the meeting. Four ME members attended. Dey contributed to the successful initiation of seven Fish Innovation Lab activities in Asia and informed the ME about issues and priorities from aquaculture and fisheries in Bangladesh and Cambodia.

ME Partner – URI

The URI ME Partner team included Elin Torell (Fish Innovation Lab deputy director through September 2022 and EAB member in 2023), Austin Humphries (East Africa specialist), Glenn Ricci (Capacity Development cross-cutting theme specialist), Karen Kent (West Africa specialist), Laura Skrobe (fisheries and program management support), and Rachel Cohn (researcher). The URI ME team supported implementation, oversight, and MEL of the Fish Innovation Lab-funded research-for-development activities. Team members participated in the Innovation Lab Cross-Cutting Theme Community of Practice, which focuses on gender and capacity development; worked with Lora Iannotti to develop the Nutrition Bait online course; participated in mission meetings with Nigeria, Zambia, Bangladesh, Kenya, and Ghana; implemented the Distant Water Fleets buy-in activity; participated in annual meetings; co-authored papers; hosted the in-person ME retreat at URI in September 2022; and implemented the Fish Innovation Lab student network.

ME Partner – WUSTL

Lora Iannotti served as the nutrition specialist, primarily providing technical inputs regarding nutrition and food security, a cross-cutting theme of the Fish Innovation Lab activities. Examples of activities by Iannotti include publishing a manuscript in Food and Nutrition Bulletin, co-authored by others from the Fish Innovation Lab, on Aquatic Animal Foods for Nutrition Security and Child Health; designed a systematic review to examine the evidence-base for the effects of mollusks and crustaceans on maternal and young child nutrition and health outcomes; organized a Borlaug Dialogue Side Event: "Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches" on October 19, 2021; and organized a panel for the annual meeting of the American Public Health Association in collaboration with ME member Kathleen Ragsdale, featuring four Fish Innovation Lab activities directly related to fish and human nutrition. Iannotti also continued to serve a voting member of the World Health Organization Guidelines Development Group for complementary feeding of the breastfed and non-breastfed child.

Regional Coordinators and Regional Specialists

The three regional coordinators (M. Gulam Hussain, Andrew Wamukota, and Sunil Siriwardena) and the three regional specialists (Madan Dey, Austin Humphries, and Karen Kent) supported Fish Innovation Lab research activities in their respective regions. The regional teams were responsible for coordinating, monitoring, and technically advising all Fish Innovation Lab research activities in their respective regions. Activities included:

1. Supported Fish Innovation Lab-funded research activities.
2. Connected with local stakeholders.
3. Engaged in broader stakeholder outreach.
4. Acted as members of the Fish Innovation Lab ME Partner team.
5. Produced publications and gave presentations.

Communications

Over the course of Phase 1, the Fish Innovation Lab ME implemented several internal and external communications activities connected to its Knowledge Management Plan:

Internal Communications

1. Stakeholders and subawardees were oriented to and supported in their contributions to the communications strategy and expectations, branding requirements, and ethical standards for photography and videography.
2. Virtual workspaces were facilitated and managed for internal communication and teambuilding. The Fish Innovation Lab used the Piestar platform for collecting and organizing monitoring data from research activities as well as subawardee activities and achievements.
3. Digital communications were used to drive awareness of the Fish Innovation Lab brand and resources and to drive organization of content on platforms.

External Communications

1. The Fish Innovation Lab website (https://www.fishinnovationlab.msstate.edu/) was developed to serve as a central hub for sharing news, research findings, communication

materials, and opportunities with Fish Innovation Lab audiences. The communications team also established and maintained active social media accounts on Facebook and X, formerly Twitter.

2. A newsletter was developed and distributed regularly to share the latest news, findings, and opportunities with Fish Innovation Lab audiences. The newsletter sign-up link was promoted widely through the Fish Innovation Lab website, social media, presentations, and events.
3. Materials such as executive summaries, success stories, and briefs were developed and promoted to showcase research impacts, findings, methods, and technologies.
4. Videos and digital media were created to explain the Fish Innovation Lab's work and highlight research results.
5. Key milestones were amplified via press releases, events, social media, website, and other channels.
6. USAID-led learning and sharing opportunities were tracked, and contributions were made to them as needed.

Website: The Fish Innovation Lab uses its website as a conduit for distributing news releases and communications materials. During Phase 1, the communications team shared 264 original stories and reposts on the website, including 46 success stories documenting the impacts and stories of Fish Innovation Lab activity participants (https://www.fishinnovationlab.msstate.edu/research/success-stories; see Appendix 3 for a complete list of success stories organized by activity). The website also houses a virtual library with over 120 resources on aquaculture and fisheries, including fact sheets, databases, manuals, university programs, professional associations, trade groups, social media outlets, mobile applications, and online courses (https://www.fishinnovationlab.msstate.edu/resources/aquaculture-fisheries).

Newsletter: The Fish Innovation Lab distributed 22 issues of the newsletter between June 2019 and September 2023 (https://www.fishinnovationlab.msstate.edu/media/newsletter), and five issues in FY23. There were 1,138 newsletter subscribers as of September 2023.

Agrilinks: Results and success stories from the Fish Innovation Lab were regularly submitted for publication on the Feed the Future Agrilinks online community, which picked up 70 stories throughout Phase 1, including 27 stories in FY23 (https://www.agrilinks.org/activities/feed-future-innovation-lab-fish).

Videos: A Fish Innovation Lab YouTube channel was created to host and share videos (https://www.youtube.com/channel/UCUAZzkCXM_c2FaiJsqFjLGQ), with 40 videos uploaded throughout Phase 1. These included:

- An overview of the Fish Innovation Lab: https://www.youtube.com/watch?v=UhRvqgWZvM8
- A series of highlights and key findings from the Quick Start Activities: https://www.youtube.com/playlist?list=PLicUnLTJ6JodRJQ5ILANPJ2L8xOz5xash and https://www.youtube.com/watch?v=373bN5zTWQw&t=15s
- A series summarizing activities and findings in each region: https://www.youtube.com/playlist?list=PLicUnLTJ6JoeEEJ9b6pSW9rcboZehNQ08
- A series developed by the Harnessing Machine Learning activity to promote innovative aquaculture approaches:

https://www.youtube.com/playlist?list=PLicUnLTJ6Joduntn_cCPsE4JRXsp81VZF

- A series of testimonials from fish farmers who participated in trainings organized by the Lean Production Systems activity: https://www.youtube.com/playlist?list=PLicUnLTJ6Jof3nEa5aHEVXOXo5hT3iXL9

As of September 2023, the Fish Innovation Lab YouTube channel had 353 subscribers, and the most popular video on seasonal activities in integrated farming had over 26,000 views (https://www.youtube.com/watch?v=wACNVQwJFco).

In addition to videos created by the ME and research teams, the Fish Innovation Lab worked with Agrilinks to create a simple how-to instructional video about the modified fish traps developed by the Samaki Salama activity (https://www.youtube.com/watch?v=BuDWufgB10I). A similar how-to video about integrated rice-fish farming based on the Aquaculture Diversification in Rural Communities activity was in production as of September 2023 and is expected to be finalized in FY24.

All videos are also available on the Fish Innovation Lab website: https://www.fishinnovationlab.msstate.edu/media/videos

Social Media: Structured social media campaigns were implemented to distribute success stories, briefs, videos, and ad hoc material generated from subaward activities and partners. As of September 2023, the Fish Innovation Lab had 789 followers on Facebook and 496 followers on X, formerly Twitter.

Publications and Presentations: In addition to the development and promotion of Fish Innovation Lab communications materials, the communications team provided editing support and branding reviews for research activity teams. Outputs from Phase 1 included 75 presentations and 52 publications.

Events: The Fish Innovation Lab organized and participated in a range of events throughout Phase 1 to promote the work and findings of the research activities (https://www.fishinnovationlab.msstate.edu/events). For example, in FY21, the ME worked with Fish Innovation Lab Nutrition Specialist Lora Iannotti to organize a virtual side event on “Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches” at the 2021 Norman E. Borlaug International Dialogue. The event had 282 registrants. In FY22, the ME collaborated with Aquaculture Africa Magazine to host a series of four webinars featuring findings from Fish Innovation Lab activities in Nigeria. The series included 391 participants. The ME also organized 11 exhibition booths at various professional meetings and conferences from 2018–2023.

Issues

This section reports on issues and lessons learned by the Fish Innovation Lab ME. Issues encountered by individual activities are reported in their respective sections.

COVID-19

In 2020 and 2021, COVID-19 and associated travel restrictions required the Fish Innovation Lab to cancel in-country visits for the Fish Innovation Lab ME and ME Partners, including site visits and trips related to communications and knowledge dissemination in Nigeria and at the World Aquaculture Society 2020 meeting in Singapore. Additionally, the team was unable to conduct videography during spring and early-summer lockdowns due to COVID-19. This delayed the release of the video on the Bangladesh Rohu Sequencing Quick Start activity and the overview

video on the Fish Innovation Lab. COVID-19 also greatly delayed the timeline for training subawardees. However, it provided an opportunity to develop online learning modules related to grants management, communications, and MEL. Although the final training package was high-quality and interactive for users, the delay of over six months in training subawardees was not ideal.

The Fish Innovation Lab annual meetings in 2020, 2021 and 2022 had to be held virtually instead of in-person. The agendas were developed to maximize networking and interactive opportunities in the virtual space, and activities were designed to gather feedback on the research strategy. Learning agenda activities were also conducted virtually instead of in-country. Unfortunately, this meant that team participation was not as broad as intended and, as a result, networking opportunities were limited. However, the Fish Innovation Lab pivoted seamlessly to the virtual space and provided a robust process by incorporating questionnaires between sessions, maximizing the time in virtual sessions, and using online platforms, such as Mural and Symposium, for interaction and input.

COVID-19 delayed field activities for most of the research activities. In-country lockdowns also restricted the regional coordinators' abilities to visit activity sites. However, the coordinators and the ME continued to communicate with activity PIs via web meetings, email, and phone.

In FY22, as the ongoing COVID-19 pandemic became more manageable globally and restrictions were lifted in many countries, the Fish Innovation Lab worked to make up for delays while continuing to capitalize on the advantages of more widespread adoption of virtual platforms and digital technologies. For instance, video conferencing equipment was installed at UI in Nigeria, and the system was used regularly for activity-related online meetings. As supply-chain disruptions eased, one of the teams in Cambodia received imported materials and advanced the construction of a wet lab required for fish feed formulation research.

The Market Analysis team published a paper on COVID-19's effects and adaptations in Bangladesh's fisheries and aquaculture sector.

By FY22, in-country teams traveled to field sites and held more in-person meetings and training events, and investigators from 13 activities traveled internationally. In July 2022, the Bangladesh Aquaculture Sector Meeting was held in person. In August, a workshop on strategies to reduce fish disease in aquaculture in Nigeria reached 93 on-site and 16 online participants. The in-person format was considered a key factor in the success of the event and follow-up activities. The in-person workshop in Ibadan Nigeria on "Nigerian Aquaculture: Status, Prospects, and Future Growth" was attended by 55 participants in October–November 2022, and the first in-person Fish Innovation Lab annual meeting in New Orleans was attended by 71 participants in February–March 2023. These meetings emphasized the value added of in-person events in conjunction with virtual platforms. As one PI highlighted, it was an invaluable opportunity to meet, learn, share findings, and identify opportunities with ME leaders, the USAID AOR, team members from all research activities, and other experts.

Other ME-Related Challenges

Despite continuous efforts from the ME to support teams, the piloting of the Integrated Insect-to-Fish Farming activity in Malawi was unable to start implementation on time, and the research goals could not be achieved in the remaining time frame. Therefore, the activity was closed in FY22.

In FY23 in Nigeria, insecurity and economic threats to food security increased dramatically. In late October 2022, the U.S. Embassy issued alerts and evacuated nonessential personnel due to threats of terrorism in the capital. At the same time, a Fish Innovation Lab Nigeria workshop

brought together more than 55 participants at the International Institute of Tropical Agriculture in Ibadan, Nigeria. USAID Nigeria and Washington did not attend in person. A field trip to research activity sites was cancelled. USAID participated in the workshop and met with the Fish Innovation Lab team virtually. The team limited field trips to UI rice-fish demonstration sites, biosecurity activity labs, and a nearby ITF feed trial farm. Nigeria also experienced currency and fuel shortages. The government introduced a new currency on February 1, 2023. Old Naira notes were no longer legal tender as of February 10, 2023. Due to inadequate availability of new currency notes, transactions had to be executed by bank transfer, causing acute food insecurity and economic distress for the population in general, and especially populations in the highly food insecure Feed the Future Zone of Influence, without links to formal banking. Nigeria's presidential elections on February 25, 2023, and state governor elections in March 2023 caused mobility restrictions. Enumerators from the Farming Insects in Nigeria activity could not be paid, and their mobility for field data collection was delayed until April. The new president removed Nigeria's fuel subsidy on May 29, 2023, causing transportation and food prices to triple. The government declared a state of emergency in July 2023 to deal with the soaring cost of food. In this context, Fish Innovation Lab research activities that sought to advance productivity (rice-fish farming, ITF feeds, and Lean management); reduce and mitigate risks to aquaculture and fisheries (improving biosecurity); and improve human outcomes demonstrated approaches that increase resilience to food security shocks and are accessible at the community level in some of the most affected zones.

Future Directions

In FY23, Fish Innovation Lab teams completed research activities from the first 5 years of implementation. In FY24, the Fish Innovation Lab will initiate a second 5-year phase. Activities for FY24 include ME staffing and planning for the second phase of implementation, selecting and launching 1-year Startup and Scaling Activities, ME domestic and international travel (including, but not limited to, attendance of the Aquaculture Africa meeting in Zambia and attendance of the Innovation Lab Regional Partners' Meeting anticipated to be in Nepal), finalizing selection of the EAB members, and developing and releasing a Request for Applications with subsequent launching of subawards.

Appendices

Appendix 1: List of Fish Innovation Lab Awarded Activities

Bangladesh

- Cryogenic Sperm Banking of Indian Major Carps and Exotic Carps for Commercial Seed Production and Brood Banking. Lead PI: Md. Rafiqul Islam Sarder, Bangladesh Agricultural University. Non-U.S. Partner Award: $499,999 *(Competitive)*
- Harnessing Machine Learning to Estimate Aquaculture Production and Value Chain Performance in Bangladesh. Lead PI: Ben Belton, Michigan State University. Award: $499,903 *(Competitive)*
- Identifying Major Sources of Foodborne Pathogens in Bangladeshi Aquaculture Value Chains and the Most Cost-Effective Risk Reduction Strategies. Lead PI: Mohammad Aminul Islam, Washington State University. Award: $463,401 *(Competitive)*
- Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement. Lead PI: Matthew Hamilton, WorldFish. Non-U.S. Partner Award: $494,885 *(Direct Commissioned)*
- Strategies for an Inclusive Aquaculture Value Chain in Bangladesh: Analysis of Market Access, Trade, and Consumption Patterns. Lead PI: Madan M. Dey, Texas State University. Award: $149,956 *(Direct Commissioned)*
- Genome Sequencing and Development of Single Nucleotide Polymorphism (SNP) Markers from Rohu in Bangladesh. Lead PI: Attila Karsi, Mississippi State University. Award: $99,999 *(Quick Start)*

Cambodia

- Development of Bighead Catfish Culture for Sustainable Aquaculture in Cambodia. Lead PI: Lyda Hok, Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture. Non-U.S. Partner Award: $496,126 *(Competitive)*
- Increasing Sustainability of Fisheries and Aquaculture for Resilience of Cambodian Communities. Lead PI: Sandra Correa, Mississippi State University. Award: $417,095 *(Competitive)*

Ghana

- Micronutrient Impact of Oysters in the Diet of Women Shellfishers. Lead PI: Brietta Oaks, University of Rhode Island. Award: $125,660 *(Direct Commissioned)*

Kenya

- Achieving Coral Reef Fishery Sustainability in East African Biodiversity and Climate Refugia Centers. Lead PI: Timothy McClanahan, Wildlife Conservation Society. Award: $380,435 *(Competitive)*
- Samaki Salama: Securing Small-Scale Fisheries in Kenya for Healthy Nutrition and Ecosystems. Lead PI: Lora Iannotti, Washington University in St. Louis. Award: $492,976 *(Competitive)*
- SecureFish: Improved Nutrition Security in Kenya Through Increased Access to and Consumption of Coastal Marine Fish. Lead PI: Lora Iannotti, Washington University of St.

Louis. Award: $100,000 *(Quick Start)*

Malawi

- Piloting Integrated Insect-to-Fish (ITF) Farming Systems in Malawi. Lead PI: Jennifer L. Pechal, Michigan State University. Award: $99,800 *(Direct Commissioned; closed due to lack of productivity)*

Nigeria

- Aquaculture and Rural Communities: Integrated Agriculture-Aquaculture as Farm Diversification Strategy. Lead PI: Matthias Halwart, FAO. Non-U.S. Partner Award: $502,148 *(Competitive)*
- Improving Biosecurity: A Science-Based Approach to Manage Fish Disease Risks and Increase the Socioeconomic Contribution of the Nigerian Catfish and Tilapia Industries. Lead PI: Mohan Chadag, WorldFish. Non-U.S. Partner Award: $597,153 *(Competitive)*
- Improving Efficiency in the Nigerian Aquaculture Sector by Employing Lean Production Systems. Lead PI: Rohana Subasinghe, WorldFish. Non-U.S. Partner Award: $462,957 *(Competitive)*
- No Longer Bugged by Feed Costs: Farming Insects as Sustainable and Scalable Aquaculture Feedstock to Improve Catfish (*Claridae*) Producers' and Consumers' Livelihoods Towards Food Security in Nigeria. Lead PI: Jennifer L. Pechal, Michigan State University. Award: $279,018 *(Competitive)*
- Nourishing Nations: Improving the Quality and Safety of Processed Fish Products in Nigeria. Lead PI: Monica Pasqualino, WorldFish. Non-U.S. partner Award: $387,143 *(Competitive)*
- From Harvest to Plate: An Analysis of the Aquaculture Post-Harvest Chain in Nigeria. Lead PI: Julius A. Nukpezah, Mississippi State University. Award: $99,964 *(Quick Start)*

Zambia

- FishFirst! Zambia: Research for Development and Scaling Staple-Fish Products for Enhanced Nutrition in the First 1,000 Days of Life. Lead PI: Kathleen Ragsdale, Mississippi State University. Award: $476,807 *(Competitive)*
- Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia. Lead PI: Bernard Hang`ombe, University of Zambia. Non-U.S. Partner Award: $144,846 *(Direct Commissioned)*
- Fish4Zambia: Assessing Facilitators and Barriers to Aquaculture and Fish Consumption in Zambia. Lead PI: Kathleen Ragsdale, Mississippi State University. Award: $99,879 *(Quick Start)*
- Population Ecology and Current Distribution Assessment of the Introduced Invasive Crayfish in the Kafue Floodplain and Lake Kariba, Zambia. Lead PI: Michael Rice, University of Rhode Island. Award: $148,493 *(Direct Commissioned)*
- Replacing Fishmeal with Single Cell Proteins in Tilapia *Oreochromis niloticus* Diets in Zambia. Lead PI: Delbert Gatlin, Texas A&M University. Award: $98,883 *(Quick Start)*

Appendix 2: Annual Indicator Results Tables

EG.3.2-1: Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training					
EG.3.2-1 Short-term agricultural sector productivity or food security training	**2020 Actual**	**2021 Actual**	**2022 Actual**	**2023 Target**	**2023 Actual**
Sex					
Male	0	516	1,316	0	1,144
Female	0	262	895	0	497
Disaggregation not available	0	0	0	0	0
Totals	**0**	**778**	**2,211**	**0**	**1,641**
Participant Type (multiple choices allowed)					
Parents/caregivers	0	0	388	0	62
Household members	0	0	14	0	42
People in government	0	47	221	0	207
USG-assisted private sector firms	0	4	56	0	54
People in civil society	0	107	148	0	129
Producers	0	620	1,379	0	1,130
Not applicable	0	0	5	0	17
Totals	**0**	**778**	**2,211**	**0**	**1,641**
Indicator result narrative	During the FY23 reporting period, a cumulative total of 1,641 individuals received short-term training across various categories. Within this beneficiary group, 1,144 were male, and 497 were female. Most of these trainings occurred during the first half of the fiscal year. Notably, producers made up 69% of the overall participant pool, demonstrating the Fish Innovation Lab's commitment to fostering technological advancements and adoption.				
Deviation from target	The absence of a specific target for short-term training in FY23 was a strategic decision aligned with the evolving focus and priorities of the activities during this period. Several key factors contributed to this deviation from setting a numerical target for short-term training: 1. Focus on Technology Transition: FY23 marked the closing phases of many activities. The primary focus shifted towards transitioning technologies from research to practical applications through workshops and demonstrations. 2. Maximizing Impact: The Fish Innovation Lab prioritized maximizing technology adoption and application in the aquaculture and fisheries. 3. Adaptation to Sectoral Needs: The Fish Innovation Lab remained flexible to meet the evolving needs of the sector, which required a stronger push for technology adoption.				

EG.3.2-1: Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training	
	4. Resource Allocation: Resources were strategically allocated to activity closeout and technology transition to ensure long-term impact and knowledge transfer. In essence, this deviation allowed the Fish Innovation Lab to concentrate efforts on ensuring the successful adoption and scaling of innovations.

EG.3-2: Number of individuals participating in USG food security programs

EG.3-2: Other project participants	2020 Actual	2021 Actual	2022 Actual	2023 Target	2023 Actual
Gender					
Male	0	1,172	2,131	400	1,836
Female	0	601	2,050	238	902
Totals	**0**	**1,773**	**4,181**	**638**	**2,738**
Age					
15-29	0	442	1,302	200	1,030
30+	0	523	2,584	438	1,581
Disaggregation not available	0	808	295	0	127
Totals	**0**	**1,773**	**4,181**	**638**	**2,738**
Participant Type (multiple choices allowed)					
Parents/caregivers	0	122	1,618	60	595
Household members	0	30	55	25	29
People in government	0	213	235	75	236
USG-assisted private sector firms	0	54	327	0	185
People in civil society	0	311	380	55	426
Laborers	0	20	297	23	83
Producers	0	1,023	1,099	400	1,178
Not applicable	0	0	170	0	6
Disaggregation not available	0	0	0	0	0
Totals	**0**	**1,773**	**4,181**	**638**	**2,738**

EG.3-2: Number of individuals participating in USG food security programs	
Indicator result narrative	In FY23, the Fish Innovation Lab made significant strides in its outreach efforts, engaging a total of 2,738 individuals through a diverse range of events aimed at promoting knowledge sharing and adoption of best practices in the field of aquaculture and fisheries. These events included informative and educational workshops on rice-fish farming, the implementation of aquaculture biosecurity BMPs, feedback meetings for country stakeholders on technology transfer and adoption, as well as exit workshops designed to capture lessons learned and provide updates on best practices from stakeholders. Out of the total participants reached, 1,836 were male and 902 were female. This signifies a balanced approach to gender inclusion, ensuring that both men and women had opportunities to benefit from the Fish Innovation Lab's initiatives. The participants belonged to various groups, with the majority (43%) being producers who play a crucial role in the aquaculture and fisheries sectors. Parents and caregivers accounted for 22% of the participants, reflecting the Fish Innovation Lab's commitment to engaging stakeholders with family responsibilities.
Deviation from target	The FY23 targets were initially projected based on several factors, including the overall remaining life-of-activity targets and proposed targets from the six activities awarded in FY21. These projections aimed to provide a realistic estimate of the Fish Innovation Lab's outreach capabilities for the fiscal year. However, the actual outreach in FY23 far exceeded the initial projections by a remarkable margin. The Fish Innovation Lab surpassed the projected target of 638 participants by an impressive 429%. This significant deviation from targets underscores the Fish Innovation Lab's effectiveness and the strong demand for its activities and events within aquaculture and fisheries communities. The Fish Innovation Lab's ability to reach and engage a larger audience than initially anticipated demonstrates its commitment to knowledge dissemination and capacity building. It also reflects the Fish Innovation Lab's adaptability in responding to the evolving needs and interests of stakeholders. This remarkable performance not only showcases the Fish Innovation Lab's success in achieving its outreach goals but also highlights its potential for even greater impact in the future.

EG.3.2-7: Number of technologies or management practices under research, under field testing, or made available for transfer as a result of USG assistance					
EG.3.2-7: Plant and animal improvement research	**2020 Actual**	**2021 Actual**	**2022 Actual**	**2023 Target**	**2023 Actual**
Status					
Phase 1: Under research	1	4	5	2	4
Phase 2: Under field testing	0	1	3	1	2
Phase 3: Made available for transfer	0	0	0	1	1
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	0	1	2
Totals	**1**	**5**	**8**	**5**	**9**

EG.3.2-7: Production systems research	**2020 Actual**	**2021 Actual**	**2022 Actual**	**2023 Target**	**2023 Actual**
Status					
Phase 1: Under research	1	4	5	0	5
Phase 2: Under field testing	0	10	7	0	8
Phase 3: Made available for transfer	0	0	14	15	15
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	1	0	5
Totals	**1**	**14**	**27**	**15**	**33**

EG.3.2-7: Social science research	**2020 Actual**	**2021 Actual**	**2022 Actual**	**2023 Target**	**2023 Actual**
Status					
Phase 1: Under research	0	1	7	2	8
Phase 2: Under field testing	1	3	3	3	4
Phase 3: Made available for transfer	0	2	3	3	3
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	1	2	1
Totals	**1**	**6**	**14**	**10**	**16**

EG.3.2-7: Number of technologies or management practices under research, under field testing, or made available for transfer as a result of USG assistance	
Indicator result narrative	In FY23, the Fish Innovation Lab's research initiatives yielded significant advancements in technology development and adoption across various domains. In FY23, there were nine Plant and Animal Improvement Research initiatives in the portfolio. Eight of these were carried over from the previous fiscal year, reflecting the sustained commitment to advancing these technologies with the addition of one in FY23. Production Systems Research efforts were bolstered with a total of 27 initiatives at the beginning of FY23. Throughout the fiscal year, six new technologies were added in this field for a total of 33, showcasing the Fish Innovation Lab's commitment to innovation. There were 14 ongoing Social Science Research initiatives at the start of FY23. Over the course of the fiscal year, an additional two initiatives were introduced for a total of 16. Collectively, the Fish Innovation Lab's research endeavors culminated in a total of 58 technologies, encompassing the diverse phases of development within the portfolio. This remarkable outcome exceeded the initial goal of 30 technologies by 197%. It is also noteworthy that the Fish Innovation Lab had eight technologies in Phase 4 (Demonstrated Uptake) in FY23, which is a substantial increase from one technology in Phase 4 during FY22. This substantial progress underscores the commitment to pushing the boundaries of innovation, technology transfer, and adoption within the aquaculture and fisheries domain.
Deviation from target	In FY23, there was a significant departure from initial targets due to a combination of factors. Targets were initially projected based on several key considerations, which included an estimation of the remaining duration of activities, especially those set to close out in FY23. This assumption led to a focus on moving technologies from Phases 1 and 2 into the latter stages of development, anticipating a logical progression. However, several unexpected opportunities for technological innovation and development emerged throughout FY23. These opportunities aligned with the Fish Innovation Lab's mission and presented compelling prospects for addressing critical challenges in aquaculture and fisheries. As a result, the Fish Innovation Lab leveraged opportunities to advance new technologies, practices, and approaches. Research teams demonstrated exceptional diligence and agility in

EG.3.2-7: Number of technologies or management practices under research, under field testing, or made available for transfer as a result of USG assistance	
	pursuing research initiatives. Several ongoing activities exhibited rapid progression from Phases 1 and 2 to the latter stages of development, including Field Testing, Advancing Towards Implementation, and Demonstrated Uptake. This acceleration was a testament to the robustness and readiness of these technologies for real-world applications. The cumulative effect of these factors was a significant deviation from the original FY23 targets. While the Fish Innovation Lab initially projected a more linear progression of technologies, the accelerated pace of innovation and adoption underscored a commitment to advancing the sector swiftly and effectively.

Indicator #3: Applied Technologies/Practices Module					
EG.3.2-24: Applied technologies	2020	2021	2022	2023	2023
	Actual	Actual	Actual	Target	Actual
Gender					
Male	0	145	1,031	0	727
Female	0	11	472	0	257
Not applicable	0	0	270	2,179	2,537
Totals	**0**	**156**	**1,773**	**2,179**	**3,521**
Age					
15-29	0	45	326	0	375
30+	0	104	1,274	0	1,669
Not applicable	0	7	173	2,179	1,477
Totals	**0**	**156**	**1,773**	**2,179**	**3,521**
Technology type (multiple choices allowed)					
Wild-caught fisheries management	0	0	732	0	62
Cultural practices	0	0	184	0	30
Wild fishing technique/gear	0	115	12	0	16
Aquaculture management	0	21	575	0	3,287
Disease management	0	3	55	0	0
Soil-related fertility and conservation	0	0	0	0	0
Water management-non-irrigation based	0	0	0	0	0
Climate mitigation	0	17	0	0	0
Climate adaptation	0	0	0	0	0
Marketing and distribution	0	0	31	0	0
Postharvest—handling and storage	0	0	0	0	57
Value-added processing	0	0	0	0	0
Pest and disease management	0	0	84	0	24
Other	0	0	100	2,179	45
Totals	**0**	**156**	**1,773**	**2,179**	**3,521**
Participant type (multiple choices allowed)					
Parents/caregivers (other)	0	2	9	0	67
Household members	0	0	106	0	49
People in government	0	8	135	0	60
USG-assisted private sector firms	0	10	99	0	187
People in civil society	0	3	333	0	21
Laborers	0	0	0	0	16
Producers	0	133	1,091	2,000	3,121
Not applicable	0	0	0	179	0
Totals	**0**	**156**	**1,773**	**2,179**	**3,521**

Indicator #3: Applied Technologies/Practices Module	
Indicator result narrative	In FY23, the Fish Innovation Lab continued its mission to disseminate and apply cutting-edge technologies to benefit the aquaculture and fisheries communities. The Fish Innovation Lab's activities reached an impressive total of 3,521 individuals, all of whom were exposed to various technologies aimed at advancing the field. This outreach had a significant impact, particularly in the adoption of aquaculture management technologies. A substantial majority (89%) were producers who were exposed to aquaculture management technologies, emphasizing the Fish Innovation Lab's focus on improving practices within this critical area. Notably, 2,537 individuals were part of the Carp Genetic Improvement activity, where they adopted the G3 genetically improved rohu. This activity represents a significant leap in genetic improvement efforts within aquaculture.
Deviation from target	The Fish Innovation Lab's FY23 targets for technology adoption were initially projected based on several factors, including the overall remaining life of activity targets and proposed targets from activities awarded in FY21. These projections aimed to provide a realistic estimate of the Fish Innovation Lab's outreach capabilities for the fiscal year. However, the actual technology adoption in FY23 exceeded the initial projections by a remarkable margin. The Fish Innovation Lab surpassed the goal of 2,179 individuals for FY23 by an impressive 162%. This substantial deviation from targets underscores the Fish Innovation Lab's effectiveness and the strong demand for its technology adoption initiatives within the aquaculture and fisheries community. The Fish Innovation Lab's ability to reach and impact a larger audience than initially anticipated demonstrates its commitment to knowledge dissemination and the application of innovative solutions. It reflects the Fish Innovation Lab's adaptability in responding to the evolving needs and interests of stakeholders. This outstanding performance not only showcases the Fish Innovation Lab's success in achieving its technology adoption goals but also highlights its potential for even greater impact in the future.

Custom: Number of individuals who have received USG supported long-term agricultural sector productivity or food security training (Custom)					
Long-term training	**2020**	**2021**	**2022**	**2023**	**2023**
	Actual	**Actual**	**Actual**	**Target**	**Actual**
Gender					
Male	0	17	24	0	29
Female	0	14	18	0	14
Totals	**0**	**31**	**42**	**0**	**43**
Training Status					
Complete	0	0	10	0	43
Continuing	0	31	21	0	0
Totals	**0**	**31**	**42**	**0**	**43**

Indicator result narrative	In FY23, the Fish Innovation Lab continued to make significant investments in building the capacity of individuals across various academic levels, including undergraduate, graduate, and PhD students as well as postdoctoral researchers. This commitment to long-term training has been a cornerstone of the Fish Innovation Lab's efforts to advance research and innovation in the fields of aquaculture and fisheries. Continuation of Previous Training: In the fiscal year, 32 individuals continued their long-term training from the previous year. These individuals represent a diverse group of learners who have been actively engaged in capacity-building activities through the Fish Innovation Lab's programs. FY23 also marked the inclusion of 11 new individuals in long-term training programs. These newcomers joined the Fish Innovation Lab's efforts to expand the pool of experts and researchers dedicated to advancing knowledge in aquaculture and fisheries. By the end of FY23, a remarkable total of 43 individuals had successfully completed long-term training programs facilitated by the Fish Innovation Lab. These individuals have acquired valuable skills and expertise that will contribute to continued growth and innovation

Custom: Number of individuals who have received USG supported long-term agricultural sector productivity or food security training (Custom)	
	within the aquaculture and fisheries sectors. The Fish Innovation Lab's commitment to nurturing talent and fostering the development of the next generation of researchers and experts is evident in its sustained efforts to provide long-term training opportunities. These programs not only contribute to the professional growth of participants but also have a broader impact on the advancement of research and innovation in aquaculture and fisheries for our partner institutions and countries.
Deviation from target	N/A

Short-Term Trainings					
Country	**Activity**	**Number Trained**			**Brief purpose of training**
		Male	**Female**	**Total**	
Nigeria	Halwart - Aquaculture Diversification in Rural Communities	171	43	**214**	These trainings aimed to enhance knowledge and skills in fish breeding, hatchery management, and integrated farming practices in specific Nigerian regions. They covered topics such as sustainable fish breeding techniques in Kebbi and Ebonyi States, value addition through combining rice and fish farming, and the long-term ecological benefits of aquaculture integration into rice-based agroecosystems. These initiatives aimed to empower participants with expertise tailored to their local contexts, contributing to more sustainable agriculture and aquaculture in Nigeria.
Nigeria	Chadag – Improving Biosecurity	6	4	**10**	These training activities were designed to advance expertise in various aspects of fisheries research and molecular diagnostics. Regular knowledge exchange meetings focused on sequencing and bioinformatics with PhD students at UI, enhancing collaborative research efforts. The Molecular Diagnostics Training Program aimed to build proficiency in advanced diagnostic techniques. Additionally, the Fish Virology Training program provided insights into fish virology, contributing to a deeper understanding of

Short-Term Trainings					
Country	Activity	Number Trained			Brief purpose of training
		Male	Female	Total	
					aquatic disease management within the context of the Fish Innovation Lab's work.
Nigeria	Pechal - Farming Insects in Nigeria	309	86	**395**	The training sessions conducted included topics such as the use of BSF in fish feeding, training of enumerators, and the successful operation of BSF colonies to produce BSFL to be incorporated into fish diets. These training programs aimed to enhance knowledge and practical skills related to sustainable aquaculture practices, including the use of alternative protein sources like BSF in fish feeding. Additionally, enumerator training was crucial for collecting accurate data and information throughout the activity. The training sessions contributed to capacity building within the aquaculture and fisheries sectors.
Nigeria	Pasqualino - Nourishing Nations	21	54	**75**	The training in Asaba, Delta State, Nigeria, aimed to enhance the skills and knowledge of fish processors from three senatorial zones in various aspects of fish processing, value addition, and investment opportunities. The participants received training on topics such as entrepreneurship, accessing financial resources for fish-related ventures, developing business plans, fish handling techniques, traditional and modern fish smoking and drying methods, fish value addition, packaging techniques, cooperative societies, and practical sessions to reinforce their learning. The objective was to empower fish processors with the tools and knowledge needed to improve their businesses and contribute to the development of the fish processing industry in the region.

Short-Term Trainings					
Country	Activity	Number Trained			Brief purpose of training
		Male	Female	Total	
Bangladesh	Islam - Foodborne Pathogens	38	12	**50**	The training sessions centered on risk analysis in the regulatory process. These sessions aimed to equip participants with the knowledge and skills needed to assess and manage regulatory risks effectively. This training was important in ensuring that regulatory processes related to aquaculture and fisheries are well-informed and compliant with established standards and guidelines.
Bangladesh	Hamilton - Carp Genetic Improvement	42	9	**51**	These trainings were conducted to provide carp hatchery managers with essential knowledge and skills related to the Carp Genetic Improvement Program. This training included genetic theory, broodfish genetics, and broodfish care, all within the context of current and forthcoming releases of genetically improved carp in Bangladesh. The aim was to enhance the expertise of hatchery managers, ensuring the successful implementation of genetic improvement practices and the overall advancement of the carp aquaculture sector in the region.
Bangladesh	Dey - Market Analysis	147	58	**205**	A series of training events was conducted with the aim of enhancing the capabilities of hatchery and nursery owners as well as aquaculture farm operators. These training sessions covered scientific and farm business management practices as well as technology adoption in aquaculture farms. The goal was to empower participants with the knowledge and skills necessary to improve the profitability and sustainability of their aquaculture businesses.
Bangladesh	Sarder - Cryogenic Sperm Banking	50	9	**59**	The final workshop served as the culmination and closing event of the activity. This workshop provided an opportunity to summarize achievements, share key findings, and discuss the outcomes and impacts of the activity with stakeholders and participants. It aimed to ensure that activity outcomes and lessons learned were effectively communicated and shared for future reference and application in related endeavors.

Short-Term Trainings					
Country	Activity	Number Trained			Brief purpose of training
		Male	Female	Total	
Kenya	Iannotti - Samaki Salama	10	12	**22**	The training sessions conducted included Community Health Volunteer training in two arms: Arm 1 focused on social marketing and basket traps, while Arm 2 focused solely on social marketing. These training programs aimed to equip the volunteers with knowledge and skills related to health promotion, particularly in the context of social marketing strategies and the use of basket traps for effective health interventions.
Cambodia	Correa - Cambodian Fisheries and Food Processing	53	53	**106**	The "Fish Processing and Preservation" workshop was organized to enhance participants' knowledge and skills in fish processing and preservation techniques, focusing on best practices and innovation in this field. The training and visiting program at MSU aimed to provide participants with exposure to the latest research and practices on fish processing and preservation, allowing them to gain insights and hands-on experience relevant to their field. The deliverable workshop on fresh fish processing and vinegar preservation was a key milestone aimed at showcasing the activity's achievements related to fresh fish processing and vinegar preservation.
Cambodia	Hok - Bighead Catfish	29	8	**37**	Several training sessions were conducted on topics related to aquaculture and fisheries, including training on water quality monitoring and feeding, fish sampling techniques, fish stocking and identification procedures, and the operation of fish feed pelletizing machines. These trainings aimed to equip participants with essential skills and knowledge in these areas, ultimately contributing to the development and enhancement of the aquaculture sector.

Short-Term Trainings					
Country	Activity	Number Trained			Brief purpose of training
		Male	Female	Total	
Kenya	McClanahan - Coral Reef Fishery Sustainability	210	77	**287**	These training sessions covered diverse topics. The "Kobo Toolbox" training focused on digital data collection. The training on "Fish Catch and Price Monitoring" aimed to improve fisheries management and market analysis. The "Institutional Review Board Training" ensured ethical research practices. Lastly, the training on "Fish Catch Weight Data Collection" enabled precise weight data collection for research purposes.
Zambia	Ragsdale - FishFirst! Zambia	48	64	**112**	FishFirst! Zambia learning events focused on critical aspects of fisheries and food security. Learning Event 1 delved into the results of ComFA+Fish Sensory Panels I-II, offering insights into product evaluations. Learning Event 3 centered on findings from the Household Hunger Scale II, specifically addressing food insecurity among Lake Kariba fishing families. Lastly, Learning Event 4 tackled the Scaling Readiness Assessment for ComFA+Fish instant porridges, shedding light on readiness factors for scaling this innovative product. These events played a vital role in advancing knowledge and strategies related to fisheries and food security in Zambia.
Zambia	Rice - Zambia Crayfish	10	8	**18**	The training was aimed to disseminate the findings of recent research on invasive crayfish in Zambia and discuss potential strategies or actions for addressing this ecological issue. By sharing research results and exploring the way forward, this training sought to raise awareness, promote understanding, and encourage collaborative efforts among stakeholders to manage the invasive crayfish issue in Zambia effectively.
TOTAL		1,144	497	**1,641**	

Long-Term Trainings								
PI and student number	**Sex**	**Home institution name**	**Degree**	**Major**	**Program end date**	**Degree granted**	**Student's home country**	**Status FY23**
Belton	M	Bangladesh Agricultural University	PhD	Aquaculture Systems and Development	2022/23	No	Bangladesh	Complete
Chadag 1	M	University of Ibadan	Master, Veterinary Public Health (MVPH)	Fish Epidemiology	2022/23	Yes	Nigeria	Complete
Chadag 2	F	University of Ibadan	MVPH	Fish Epidemiology	2022/23	Yes	Nigeria	Complete
Correa 1	M	Royal University of Phnom Penh	MS	Biodiversity	2023	Yes	Cambodia	Complete
Correa 2	F	Royal University of Phnom Penh	MS	Food Science & Technology	2023	Yes	Cambodia	Complete
Halwart 1	M	University of Ibadan	PhD	Agriculture Economics	2023	No	Nigeria	Complete
Halwart 2	F	University of Ibadan	PhD	Fisheries Management	2023	No	Nigeria	Complete
Halwart 3	M	Usmanu Danfodiyo University, Sokoto	MS	Fisheries Ecology	2021	No	Nigeria	Complete
Halwart 4	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Complete
Halwart 5	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Complete
Halwart 6	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Complete
Halwart 7	M	Federal University of Technology Owerri	MS	Fish Nutrition	2021	No	Nigeria	Complete
Halwart 8	M	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Complete
Hang`ombe 1	F	University Zambia	PhD	Research Training	2024	No	Zambia	Complete
Hang`ombe 2	M	University Zambia	MS	Research Training	2023	No	Zambia	Complete

Long-Term Trainings								
PI and student number	**Sex**	**Home institution name**	**Degree**	**Major**	**Program end date**	**Degree granted**	**Student's home country**	**Status FY23**
Hang`ombe 3	M	University Zambia	MS	Research Training	2023	No	Zambia	Complete
Hok 1	M	Royal University of Agriculture	PhD	Agricultural Science	2023	No	Cambodia	Complete
Hok 2	M	Royal University of Agriculture	Undergrad	Agricultural Science	2023	No	Cambodia	Complete
Hok 3	M	Royal University of Agriculture	Undergrad	Agricultural Science	2023	No	Cambodia	Complete
Hok 4	M	Royal University of Agriculture	Undergrad	Agricultural Science	2023	No	Cambodia	Complete
Hok 5	M	Royal University of Agriculture	Undergrad	Agricultural Science	2023	No	Cambodia	Complete
Hok 6	M	Royal University of Agriculture	Undergrad	Agricultural Science	2023	No	Cambodia	Complete
Hok 7	M	Royal University of Agriculture	Undergrad	Agricultural Science	2024	No	Cambodia	Complete
Hok 8	M	Royal University of Agriculture	Undergrad	Agricultural Science	2025	No	Cambodia	Complete
Hok 9	M	Royal University of Agriculture	Undergrad	Agricultural Science	2026	No	Cambodia	Complete
Hok 10	F	Royal University of Agriculture	Undergrad	Agricultural Science	2027	No	Cambodia	Complete
Islam 1	M	University of Dhaka	MS	Fisheries and Biotechnology	2022/23	No	Bangladesh	Complete

Long-Term Trainings								
PI and student number	**Sex**	**Home institution name**	**Degree**	**Major**	**Program end date**	**Degree granted**	**Student's home country**	**Status FY23**
Islam 2	F	University of Dhaka	MS	Fisheries and Biotechnology	2022/23	No	Bangladesh	Complete
McClanahan 1	F	University of Rhode Island	PhD	Biological and Environmental Sciences	Jul-05	No	USA	Complete
Oaks 1	M	University of Ghana	PhD	Research Training	2024	No	Ghana	Complete
Pasqualino 2	F	University of Calabar	MS	Nutrition and Food Science	2022/23	No	Nigeria	Complete
Pasqualino 3	M	University of Calabar	MS	Nutrition and Food Science	2021/22	No	Nigeria	Complete
Pechal 1	M	University of Ibadan	PhD	Microbial Analysis	2025	No	Nigeria	Complete
Pechal 2	M	University of Ibadan	PhD	Agricultural Economics	2023	No	Nigeria	Complete
Rice 1	F	University Zambia	MS	Research Training	2022	No	Zambia	Complete
Sarder 1	M	Bangladesh Agricultural University	PhD	Fish Breeding and Biotechnology	2024	No	Bangladesh	Complete
Sarder 10	F	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	Complete
Sarder 11	F	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	Complete
Sarder 2	M	Bangladesh Agricultural University	MS	Fish Breeding and Biotechnology	2021	No	Bangladesh	Complete
Sarder 4	M	Bangladesh Agricultural University	PhD	Fish Breeding and Biotechnology	2024	No	Bangladesh	Complete
Sarder 7	M	Bangladesh Agricultural University	MS	Fish Breeding and Biotechnology	2023	No	Bangladesh	Complete
Sarder 8	M	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	Complete

Long-Term Trainings								
PI and student number	**Sex**	**Home institution name**	**Degree**	**Major**	**Program end date**	**Degree granted**	**Student's home country**	**Status FY23**
Sarder 9	M	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	Complete

Appendix 3: Success Stories

Fish Innovation Lab success stories by research activity and year are presented here.

1. **Activity Title:** From Harvest to Plate: An Analysis of the Aquaculture Postharvest Chain in Nigeria

   U.S. PI: Julius A. Nukpezah, Mississippi State University

   Aquaculture and Public Health in Nigeria (FY2020)

2. **Activity Title:** Replacing Fishmeal with Single-Cell Proteins in Tilapia (*Oreochromis niloticus*) Diets in Zambia

   U.S. PI: Delbert Gatlin, Texas A & M University

   Increased Sustainability and Research Capacity for Tilapia Aquaculture in Zambia (FY2020)

3. **Activity Title:** Genome Sequencing and Development of Single Nucleotide Polymorphism Markers from Rohu in Bangladesh

   U.S. PI: Attila Karsi, Mississippi State University

   Students Trained as Enumerators to Assess Farmer Needs for Rohu Genetic Improvement (FY2020)

4. **Activity Title:** Aquaculture and Rural Communities: Integrated Agriculture-Aquaculture as Farm Diversification Strategy

   Lead PI: Matthias Halwart, Food and Agricultural Organization of the United Nation

   From Rice to Fish: Boosting Productivity and Nutrition Through Farm Diversification (FY2023)

   Rice-Fish Farming Increases Yield, Improves Household Nutrition and Income for Nigerian Families (FY2023)

5. **Activity Title:** No Longer Bugged by Feed Costs: Farming Insects as Sustainable and Scalable Aquaculture Feedstock to Improve Catfish (*Claridae*) Producers' and Consumers' Livelihoods Towards Food Security in Nigeria

   Lead PI: Jennifer Pechal, Michigan State University

   Farming Black Soldier Fly for Catfish Feed in Nigeria to Reduce Feed Costs (FY2023)

6. **Activity Title:** Improving Efficiency in the Nigerian Aquaculture Sector by Employing Lean Production Systems

   Lead PI: Rohana Subasinghe, WorldFish

   Onaduja Transformed her Business With Lean Tools and Helped Others do the Same (FY2023)

   Hussaini Used Lean Skills to Improve Record Keeping and Aquaculture Productivity (FY2023)

   Oluyemi Used Lean Tools to Identify and Address the Causes of Fish Mortality (FY2023)

   Otomiewo Used Lean Tools to Turn Around the Aquaculture Business of her Farming Cluster (FY2023)

   Fish Innovation Lab Trainees Identify Areas of Waste and Make Improvements at the

Farm Level (FY2022)

Lean Subject Matter Experts Train Nigerian Fish Farmers to Improve Aquaculture Productivity (FY2021)

Improving the Efficiency of Aquaculture Farms in Nigeria (FY2021)

7. **Activity Title:** Development of Bighead Catfish (*Clarias macrocephalus*) Culture for Sustainable Aquaculture in Cambodia

   Lead PI: Lyda Hok, Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture

   Bighead Catfish Nutrition Research and Training Builds Capacity Through Installation of a Feed Pelletizing Machine (FY2023)

   Training Cambodian Fisheries Students and Faculty on Aquaculture to Build Capacity (FY2021)

8. **Activity Title:** Achieving Coral Reef Fishery Sustainability in the East African Biodiversity and Climate Refugia Center

   Lead PI: Timothy McClanahan, Wildlife Conservation Society

   Increasing Knowledge of Fisheries Status Through Community Stock Assessment Training (FY2022)

   Increasing the Capacity for Achieving Sustainable Fisheries Management in Kenya (FY2021)

9. **Activity Title:** Cryogenic Sperm Banking of Indian Major Carps and Exotic Carps for Commercial Seed Production and Brood Banking

   Lead PI: Md. Rafiqul Islam Sarder, Bangladesh Agricultural University

   Dreams of Becoming a Successful, Quality Fish Seed Producer are Realized (FY2023)

   Early Successes Inspire Fish Hatchery Owners to Adopt Cryopreservation Technology (FY2022)

   Quality Seed Production Using Cryopreserved Sperm in Fish Hatcheries Becomes a Reality in Bangladesh (FY2021)

10. **Activity Title:** Increasing Sustainability of Fisheries and Aquaculture for Resilience of Cambodian Communities

    Lead PI: Sandra Correa, Mississippi State University

    Fishing is for Girls: Rural Matriarch Fishes for Family and Research (FY2023)

    Building Capacity: Graduate Student in Cambodia Working on the First Nutritional Database for Fish (FY2022)

    Fishers in Cambodia use Citizen Science Program to Improve Their Fishery (FY2021)

11. **Activity Title:** Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement

    Lead PI: Matthew Hamilton, WorldFish

    Genetically Improved Rohu is Commercially Available and in High Demand in Bangladesh (FY2022)

Genetically Improved Rohu Carp is Now in the Hands of Bangladeshi Farmers (FY2021)

12. **Activity Title:** Improving Biosecurity: A Science-Based Approach to Manage Fish Disease Risks and Increase the Socioeconomic Contribution of the Nigerian Catfish and Tilapia Industries

    Lead PI: Mohan Chadag, WorldFish

    An Ounce of Prevention is Worth a Pound of Cure: International Training Helps Aquaculture Researchers Enhance Early Detection Skills (FY2023)

    E-AquaHealth Web Platform: An Aquaculture Intervention (FY2022)

    Integrating Digital Learning Tools for Long Distance Team Training During the COVID-19 Crisis (FY2021)

13. **Activity Title:** Identifying Major Sources of Foodborne Pathogens in Bangladeshi Aquaculture Value Chains and the Most Cost-Effective Risk Reduction Strategies

    Lead PI: Mohammad Aminul Islam, Washington State University

    Fish Value Chain Survey Informs Future Interventions to Mitigate Foodborne Pathogens (FY2022)

    Improving Capacity in Bangladesh to Detect Fecal Pathogens in Aquaculture (FY2021)

14. **Activity Title:** Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia

    Lead PI: Bernard Hang`ombe, University of Zambia

    Fish Disease Investigation Increases Disease Awareness Among Small-Scale Fish Farmers (FY2022)

15. **Activity Title:** SecureFish: Improved Nutrition Among Vulnerable Populations in Kenya Through Increased Access to and Consumption of Sustainable Fish Foods

    U.S. PI: Lora Iannotti, Washington University in St. Louis

    Increased Fish Intake Improves Brain Development for Young Children (FY2020)

16. **Activity Title:** Fish4Zambia: Assessing Facilitators and Barriers to Aquaculture and Fish Consumption in Zambia

    U.S. PI: Kathleen Ragsdale, Mississippi State University

    Fish4Zambia Builds Capacity Through Student Fieldwork Training (FY2020)

17. **Activity Title:** Harnessing Machine Learning to Estimate Aquaculture Production and Value Chain Performance in Bangladesh

    Lead PI: Ben Belton, Michigan State University
    Machine Learning Tool Paving the Way to Modernize Aquaculture Statistics in Bangladesh (FY2022)

    Shrimp Farming and Research in Bangladesh Adapts to COVID-19 Pandemic (FY2021)

18. **Activity Title:** Nourishing Nations: Improving the Quality and Safety of Processed Fish Products in Nigeria

    Lead PI: Monica Pasqualino, WorldFish

    Fish Processors in Nigeria Apply New Skills From Training to Improve Their Products

and Businesses (FY2022)

Nutrition and Food Safety Training Make a Difference for Nigerian Fish Processors (FY2021)

19. **Activity Title:** FishFirst! Zambia: Research for Development and Scaling Staple-Fish Products for Enhanced Nutrition in the First 1,000 Days of Life

    Lead PI: Kathleen Ragsdale, Mississippi State University

    A Community Health Worker Becomes a FishFirst! Zambia Champion and Local Catalyst for Change (FY2022)

20. **Activity Title:** Samaki Salama: Securing Small-Scale Fisheries in Kenya for Healthy Nutrition and Ecosystems

    Lead PI: Lora Iannotti, Washington University in St. Louis

    Kenyan Fisherman Improves his Livelihood and Family Wellbeing Through Modified Basket Traps and Training (FY2023)

    Samaki Salama: Helping a Grandmother in Kenya Provide Better Nutrition to her Granddaughter (FY2023)

    Individualized Nutrition Education and Group Cooking Demonstrations Increase Knowledge on Fish Consumption Among Caregivers (FY2022)

    Modified Fishing Traps and Fisher Workshops Promote Fish Consumption and Sustainable Fishing (FY2022)

    Personalized Home Visits Increase Knowledge on the Importance of Consuming Fish in Coastal Kenya (FY2021)

21. **Activity Title:** Population ecology and current distribution assessment of the introduced invasive crayfish in the Kafue floodplain and Lake Kariba, Zambia

    Lead PI: Michael Rice, University of Rhode Island

    Know the Risks: Researching Invasive Crayfish in Zambia Leads to a Future Career in Aquaculture Research (FY2023)

22. **Activity Title:** Strategies for an Inclusive Aquaculture Value Chain in Bangladesh: Analysis of Market Access, Trade, and Consumption Patterns

    Lead PI: Madan M. Dey, Texas State University

    Aquaculture Training Teaches Bangladesh Farmers Business Practices to be More Profitable (FY2022)

23. **Activity Title:** Micronutrient Impact of Oysters in the Diet of Women Shellfishers

    Lead PI: Brietta Oaks, University of Rhode Island

    Oysters Have Potential as a Rich Source of Micronutrients in Ghana (FY2023)

Appendix 4: Environmental Management and Mitigation Report

Initial environmental examination (IEE) condition	Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
Activity Name: Aquaculture and rural communities: Farm diversification strategy through integrated agriculture-aquaculture systems and nutrition-sensitive value chains for better nutrition outcomes **Sub-Activity:** Development of suitable integrated rice-fish production technology through participatory research actions **PI: Halwart**			
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored. Activities should be evaluated to ensure that there are no risks related to • Poor siting and improper pond construction. • Aquaculture operations, which can cause water contamination, sedimentation; farmed animal escape; unhealthy fish in the aquaculture ponds due to overcrowding; and overharvesting of wild eggs, larvae, juveniles, and adults for aquaculture production.	**Mitigation** Implement environmental BMPs for agriculture and aquaculture. Training provided to staff to ensure adherence to the regulations. Use already cleared land and reuse existing ponds or rice paddies whenever possible. When possible, select native versus exotic species. Use hatcheries to provide eggs, larvae, etc. for aquaculture operations. Protect against escapes of farmed animals. Implement protocols for maintaining fish health.	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the Institutional Animal Care and Use Committee (IACUC) and environmental health and safety (EH&S) office or equivalent, as appropriate.	**Reporting** Farmers were provided with training and guidance for proper modification of existing rice fields to include aquaculture. Farmers were trained in BMPs for rice-fish co-culture. The dikes of the adapted rice fields were raised high to prevent the escape of fish.
Activity Name: Cryogenic sperm banking of Indian major carps and exotic carps for commercial seed production and brood banking **Sub-Activity:** Development of donor broodstocks of IMCs and three exotic carps **PI: Sarder**			

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored. Precautions must be taken to avoid overharvesting of fry for the broodstock.	**Mitigation** • A small amount of larvae/fry will be collected from rivers, so there will be no negative impact on natural stocks. • The three exotic carps are being cultured along with IMCs in Bangladesh for about the last three decades in a polyculture fashion and there is no negative effect of the exotic carps on IMCs. • The exotic carps do not breed in natural water bodies and the seeds of them are always artificially produced in hatcheries.	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	**Reporting** Broodstocks of three IMCs, Rohu, Catla and Mrigal of Halda and Padma river-origin were developed through rearing in ponds at BAU campus. Similarly, broodstocks of three exotic carps, Silver carp, Bighead carp, and Grass carp, were developed by rearing imported fingerlings from China by DoF in ponds at the BAU campus. All the fish were reared in confined ponds with supplementary feeds and there was no risk of escaping to open water bodies.	
Activity Name: Cryogenic sperm banking of Indian major carps and exotic carps for commercial seed production and brood banking **Sub-Activity:** Production of seeds of carps in hatcheries by use of cryopreserved sperm and assessment of their quality through growth and DNA microsatellite analysis **PI: Sarder**				
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored.	**Mitigation** The team will adhere to good laboratory and biosafety practices. Seeds will be produced using cryopreserved sperm in hatcheries and will be	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as	**Reporting** Seeds of three IMCs and three exotic carps were produced using cryopreserved sperm collected from the developed cryogenic sperm bank in 18 government and private hatcheries in Mymensingh, Faridpur, Jashore and Barishal regions. The seeds were reared in the respective hatcheries and also in a few technology adoption hatcheries and fish farms with supplementary feeds. Sampling of fish was carried out monthly.	

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
Precautions must be taken to avoid exotic species escaping to natural waters.	reared very carefully in confined conditions (ponds). So, there will be no chance of escape of exotic carps to natural waters. However, if they escape to natural waters during flooding (if any), it will have no negative effects on indigenous species.	appropriate.	The sampling data revealed comparatively higher growth in cryopreserved sperm-originated fish (Rohu, Catla, Mrigal, Silver carp, Bighead carp and Grass carp) than their respective controls. Fin samples of seeds and their donor parents were taken and preserved for DNA analysis. DNA was extracted from some collected samples and used for PCR amplification and Polyacrylamide gel electrophoresis. The above activities did/do not have any risks to the environment.	
Activity Name: Cryogenic sperm banking of Indian major carps and exotic carps for commercial seed production and brood banking **Sub-Activity:** Evaluation of the adoptability of technology by the stakeholders **PI: Sarder**				
IEE Condition	**Mitigation**	**Monitoring**	**Reporting**	
Category: Analyses, studies, academic or research workshops and meetings. Precautions must be taken to avoid exotic species escaping to natural waters.	Growth performance of seeds of exotic carps produced using cryopreserved sperm will be carried out in ponds that are not flood-prone. However, if they escape to natural waters during flooding (if any), it will have no negative effects on the indigenous species.	Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	Seeds of Rohu, Catla, Mrigal, Silver carp, Bighead carp and Grass carp were produced in government and private hatcheries in four regions, and a portion of the seeds were stocked in ponds in four technology adoption hatcheries and fish farms and reared with supplementary feeds. The control groups were stocked separately in the respective farms. The fish of both experimental and control groups were sampled monthly for comparing their growth performances. There was no risk of escaping of the stocked fish to open water bodies. There were and are no negative effects of the above activities on the environment.	
Activity Name: No longer bugged by feed costs: Farming insects as sustainable and scalable aquaculture feedstock to improve catfish (*Clariidae*) producers' and consumers' livelihoods towards food security in Nigeria **Sub-Activity:** Co-optimize integrated insect-to-feed farming system infrastructure to increase local production of fish while minimizing costs of production **PI: Pechal**				

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored. However, activities should be evaluated to ensure that there are no risks related to • Poor siting and improper pond construction. • Aquaculture operations, which can cause water contamination, sedimentation; farmed animal escape; unhealthy fish in the aquaculture ponds due to overcrowding; and overharvesting of wild eggs, larvae, juveniles, and adults for aquaculture production.	**Mitigation** • Implementation of environmental BMPs for agriculture and aquaculture. • Training provided to staff to ensure adherence to the regulations. • Use already cleared land and reuse existing ponds whenever possible. • Use lower stocking densities and less intensive production systems. • When possible, select native versus exotic species. • Use hatcheries to provide eggs, larvae, etc. for aquaculture operations. • Protect against escapes of farmed animals. • Implement protocols for maintaining fish health.	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	**Reporting** Efforts were taken to ensure that risks were reduced to the bare minimum. The activity used plastic tanks for fish feeding demonstrations, and they were properly sited where wastewater drained easily and did not cause contamination or constitute a nuisance. The BSFL that were reared are not harmful and they are not vectors of diseases. Rather, they help in decomposing organic matter producing rich animal protein and rich organic fertilizer (Frass). The adult insect of the BSF does not hurt anyone. It does not sting. When they die, they can also be fed to fish just as the larvae are fed to catfish.	
Activity Name: Development and investigation of the delivery mode of a multivalent bacterial fish vaccine in Zambia **Sub-Activity:** Clinical trials **PI: Hang'ombe**				

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored. Precautions must be taken to ensure biosafety and avoid accidental water contamination and spread of bacteria. Use of secured laboratories for pathogen isolation and animal experimentation.	**Mitigation** The team will adhere to standard laboratory and biosafety practices. PIs should be trained in biosafety and standard procedures for conducting research with bacterial pathogens. Use of technical staff trained to handle biological and hazardous materials. Training provided to staff to ensure adherence to the regulations.	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	**Reporting** The PI monitored laboratory practices, developed experimental protocols, and monitored practices. Adherence to appropriate protocols was completed by the Departmental Chief Scientist. A detailed description of the proposed use of fish in the study was prepared by the researchers and approved by the National Ethics Review Committee. The activities were only undertaken after approval. The applicable conditions on the use of animals were according to IACUC. Approval letters were provided. The laboratory had safety cabinets to ensure biosafety practices were followed with proper markings. The students were trained in standard practices before undertaking laboratory usage. During field sampling, all disposable biological materials were placed in autoclavable bags for incineration at the university incineration facility after autoclaving. The technical staff working with students were trained to handle biological and hazardous materials as approved through their registration by the Health Professionals Council of Zambia.	
Activity Name: Piloting integrated insect-to-fish (ITF) farming systems in Malawi **Sub-Activity:** Evaluate changes in pond yield and productivity resulting from different mixes of BSF meal in fish feed. **PI: Pechal**				
IEE Condition Category: Controlled experimentation exclusively for the purpose of research and field evaluation, which are confined to small areas and carefully monitored. However, activities should be evaluated to ensure that	**Mitigation** • Implementation of environmental BMPs for agriculture and aquaculture. • Training provided to staff to ensure adherence to the regulation.	**Monitoring** Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	**Reporting** This activity did not make progress starting up and was closed in FY22.	

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
there are no risks related to • Poor siting and improper pond or cage construction • Aquaculture operations, which can cause water contamination, sedimentation; farmed animal escape; unhealthy fish in the aquaculture ponds or cage due to overcrowding; and overharvesting of wild eggs, larvae, juveniles, and adults for aquaculture production.	• Use already cleared land and reuse existing ponds whenever possible. • Use lower stocking densities and less intensive production systems. • When possible, select native versus exotic species. • Use hatcheries to provide eggs, larvae, etc. for aquaculture operations. • Protect against escapes of farmed animals (e.g., insects). • Implement protocols for maintaining fish health.			
Activity Name: Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement **Sub-Activities:** Output 1: Performance analysis from dissemination of genetically improved rohu at scale to hatcheries and farmers; Output 3: New generations of improved carps **PI: Hamilton**				
IEE Condition **Negative determination with conditions:** Activities should be evaluated to ensure that there are no risks related to • Biosafety might be disrupted if invasive	**Mitigation** • Introduction of invasive alien fish species will be avoided. • Maintaining broodstock purity will be promoted, and	**Monitoring** • List of approved fish species to be promoted/developed. • Guidelines for maintaining the purity of broodstock developed.	**Reporting** WorldFish maintains closed genetically improved populations of catla (indigenous), rohu (indigenous), and silver carp (exotic, China). WorldFish sourced all fish in these populations from Bangladeshi rivers or hatcheries. Details of the origin and composition of founder populations have been published: • Hamilton, M.G., Mekkawy, W., Barman, B.K., Alam, M.B.,	

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
alien species are introduced. • Fish seed adulteration may take place. • Food safety might be disrupted if harmful inputs/chemicals are used and/or appropriate cleaning, disinfection, and waste management are not followed.	inbreeding or other causes of seed adulteration will be avoided. • Using inputs in seed production that are not approved by the Fish Hatchery Rules, 2011, and • U.S. Food and Drug Administration will be avoided. • Appropriate cleaning, disinfection, and waste management will be followed.	• Number of hatcheries that follow the guidelines for maintaining the purity of broodstock. • Guidelines for cleaning, disinfection, and waste management for hatchery developed. • Log sheets for recording day-to-day hatchery operations developed. • Monitor the number of hatcheries that use only approved inputs and follow appropriate cleaning, disinfection, and waste management procedures. • Number of hatcheries that update the log sheets for recording day-to-day operations including waste management.	Karim, M., Benzie, J.A.H. 2021. "Genetic relationships among founders of a silver carp *(Hypophthalmichthys molitrix*) genetic improvement program in Bangladesh." Aquaculture, 736715, 2021. https://doi.org/10.1016/j.aquaculture.2021. 736715 • Hamilton MG, Mekkawy W, Benzie JAH (2019a) Sibship assignment to the founders of a Bangladeshi *Catla catla* breeding population. Genet Sel Evol 51(1):17. https://doi.org/10.1186/s12711-019-0454-x • Hamilton, M.G., Mekkawy, W., Kilian, A., Benzie, J.A.H. (2019b). "Single Nucleotide Polymorphisms (SNPs) reveal sibship among founders of a Bangladeshi rohu (*Labeo rohita*) breeding population." Frontiers in Genetics 10, no. 597. https://doi.org/10.3389/fgene.2019.00597 WorldFish tracks the ancestry of all fish in its genetically improved populations. Individual fish are tagged with passive integrated transponders (i.e., PIT tagged), and the family identities of all fish in these populations are maintained, allowing each fish's ancestry to be traced back to the founders of the closed populations. Fish records (individual identifiers, parental identifiers, measurement data, etc.) are maintained in the WorldFish Carp Genetic Improvement Database: • Hamilton, M.G. (2021). WorldFish Carp Genetic Improvement Program Data Management System (Version 3): Data input. P. 47. WorldFish. Program Report, Penyang, Malaysia. https://hdl.handle.net/20.500.12348/4869 Only fish at the WorldFish Carp Genetic Improvement Facility located at Talbaria, near Jashore, Bangaldesh, are tagged to allow each fish's ancestry to be traced back to individual fish in the founder populations. However, untagged spawn from known families (the G3 multiplier subpopulation) has been distributed to external hatcheries. Details of the quantities of spawn from each family distributed to each external partner hatchery is maintained in the WorldFish Carp Genetic Improvement Database (see above,	

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
			https://hdl.handle.net/20.500.12348/4869). Every effort has been made to track sales of these fish to additional non-partner hatcheries. Details of the composition and performance of the G3 multiplier disseminated to partner hatcheries in 2022 are to be published soon: • Hamilton, M.G., Yeasin, M., Alam, M.B., Ali, M.R., Fakhruddin, M., Islam, M.M., Barman, B.K., Shikuku, K.M., Shelley, C.C., Rossignoli, C.M., Benzie, J.A.H. (in prep). On-farm performance of genetically improved rohu (*Labeo rohita*) in Bangladesh. Frontiers in Aquaculture. Log sheets for recording day-to-day hatchery operations were developed. The hatchery facility at the WorldFish Carp Genetic Improvement Facility is only used for a small number of spawning each year (generally six). Log sheets recording environmental parameters, parents of families etc. are maintained at the time of spawning. Spawning is undertaken according to the Worldfish Standard Operating Procedures: • Hamilton, M., Alam, M.B., Rajts, F. 2020. “Spawning carp genetic improvement program families standard operating procedure.” WorldFish Internal Report, Penang, Malaysia. Thorough cleaning and disinfection practices are documented and observed prior to, and between, spawning events in the WorldFish Carp Genetic Improvement Facility hatchery. However, “cleaning, disinfection, and waste management” practices are not yet fully integrated into the “spawning carp genetic improvement program families standard operating procedure.” Detailed records of environmental parameters, fish movements, water movements, fish sampling, etc. are maintained for each nursery, grow out, and broodstock pond adjoining the hatchery at the WorldFish Carp Genetic Improvement Facility: • Hamilton M., Rajts F., Collis W., Shanta S., Alam M. & Kabir M. (2020) WorldFish carp genetic improvement	

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
			program electronic pond book guide. WorldFish, Penang, Malaysia. https://hdl.handle.net/20.500.12348/4188 Realistically, WorldFish can only closely monitor and enforce hatcheries' compliance with approved inputs and following appropriate cleaning, disinfection, and waste management procedures, including updating the log sheets for recording day to day operations of waste management at its own facility (i.e., one).	
Activity Name: Increasing sustainability of fisheries for resilience of Cambodian communities **Sub-Activity:** Improve sustainable fisheries management by implementing a citizen science harvest-monitoring program and digital platform for documentation and analysis of harvest to assess change. **PI: Correa**				
IEE Condition Category: Analyses, studies, academic or research workshops and meetings. Research, extension, and capacity building should integrate and promote general awareness of the environmental, health, and safety risks presented by fishing and coastal economic activities and make appropriate choices and measures to manage these risks.	**Mitigation** Fishers will be trained to monitor how fish populations change after the implementation of community fisheries agreements. The research team will review and screen all policy documents, advocacy materials, and training curricula to ensure that they are environmentally sound and promote sustainable fishing practices. They will teach fisheries management concepts and emphasize the importance of keeping fishing within the maximum sustainable yield to ensure fish for future generations.	**Monitoring** In addition to ensuring that training materials do not promote unsustainable practices, the team will monitor unexpected changes in harvesting practices (e.g., increase in yield of currently overharvested species and fishing activities in locations banned per community-based fishing agreements).	**Reporting** In FY21, train-the-trainer activities emphasized that the selection of fishers to participate in the citizen science data-collection program must not lead to changes in fishers' behavior in terms of fishing location and frequency. The team discussed the potential for such behavioral change during training sections and requested the Cambodian team to discuss it with fishers during field training sections and community meetings. The team conducted fisheries management workshops to discuss how to achieve sustainable fishing practices. The team completed 24 months of data collection by February 28, 2023. On May 28, 2023, it completed data digitalization and uploaded data onto the iFish Sre Ambel App (https://ifish.shinyapps.io/ifish/) for analyses. The team conducted visual spatial analyses of fishing practices every 6 months. Based on the fishing trips map, the team has not seen signs of change in harvest practices over the 2-year duration of the program.	

Initial environmental examination (IEE) condition	Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
Activity Name: Samaki Salama: Securing small-scale fisheries in Kenya for healthy nutrition and ecosystems **Sub-Activity:** Measure the impact of fishing gear cooperatives on gear modification and diversification as well as catch dynamics and earnings **PI: Iannotti**			
IEE Condition Category: Analyses, studies, academic or research workshops and meetings. Research, extension, and capacity building should integrate and promote general awareness of the environmental, health, and safety risks presented by fishing and coastal economic activities and make appropriate choices and measures to manage these risks.	**Mitigation** Fishers will be trained in sustainable fisheries management. The importance of keeping fishing within the maximum sustainable yield will be emphasized.	**Monitoring** Review of training curricula. Document fishers trained on sustainable fishing practices. Document use and adherence of modified traps vs traditional traps.	**Reporting** • The team trained fishers in sustainable fisheries management and completed monitoring of the training curriculum in FY22. • Modified traps with escape gaps were distributed and this was documented. • Monthly meetings were held with fishers who had received traps to ensure proper use. • Fish catch data was collected to assess the difference since the use of modified traps vs. the traditional traps. • Fishers reported increased fish catch and subsequent increased income.
Activity Name: Achieving coral reef fishery sustainability in the East African biodiversity and climate refugia center **Sub-Activity:** Improve the management capacity of communities to monitor fisheries and habitats and use this information for adaptive management **PI: McClanahan**			
IEE Condition Category: Education, technical assistance, or training programs. Research, extension, and capacity building should integrate and promote general awareness of the	**Mitigation** Co-production of information and management intended to reverse the current downward trends and reduce environmental impacts.	**Monitoring** • Generated knowledge by targeted fisheries communities through participatory	**Reporting** • Catch, incomes, and material style of life parameters were monitored over the 3-year period to examine changes. Secondly, perceptions of governance and management restrictions were compared across time. Levels of knowledge about fisheries were evaluated to better understand information and training needs. Finally, there were surveys on preferred future scenarios to evaluate societal goals.

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
environmental, health, and safety risks presented by fishing and coastal economic activities and appropriate choices and measures to manage these risks.		fisheries measurements and management. • Conservation of marine resources and expected increase in fish production and incomes. • Benefits sharing from sustainable use of fisheries resources.	• Eight individuals were trained in Institutional Review Board minimal standards in preparation for the pre- and post-household surveys, with three from the private sector and a government official participating in questionnaire administration. • Feedback meetings were held in five activity sites in addition to meetings with government partners and other communities within the Vanga Shimoni area (Diani-Chale). The team communicated summaries from collated fish landing and socioeconomic surveys to enhance their awareness on the status of the resources within the seascape versus the other region on the Kenyan coast. • An additional 71 community and BMU members from the Diani-Chale area participated in fisheries literacy tests. They were trained on the use of mobile phones in data collection and data collection protocols to help replication of activities in other sites of the Vanga Shimoni seascape. The training also strengthened capacity for better fishing practices to achieve sustainable fishing and improved their skills in modern data collection tools using Kobo Collect to provide data to help monitor the fish catch along their seascape. • A total of 11 community members adopted the use of applied technology (Atlan and Kobo Collect Apps) installed on their mobile phones and used these in monthly fish landing monitoring data collection and coding.	

Activity Name: FishFirst! Zambia: Research for development and scaling staple-fish products for enhanced nutrition in the first 1,000 days of life

Sub-Activity: Explore potential of upgrading the small pelagic fish value chain via improving processing, storage, and trading methods to reduce postharvest losses and improve food safety

PI: Ragsdale

IEE Condition	Mitigation	Monitoring	Reporting
Category: Analyses, studies, academic or research workshops and meetings. Training and extension	Research, extension, and capacity building will integrate and promote general awareness of the environmental, health, and	Review and screening of research protocols, advocacy materials, and training curricula to ensure that they are environmentally sound.	Nothing to report. Data collection during the ComFA+Fish Sensory Panels I-III Evaluations among participants did not have a negative environmental impact.

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
activities promoting postharvest loss and fish processing technologies may result in unsustainable use of fish and other natural resources (e.g., fuelwood) if message is poorly conceived and conveyed.	safety risks presented by fishing, onboard handling, and postharvest processing. It will integrate appropriate choices and measures to manage associated risks.			

Activity Name: Nourishing Nations: Improving the quality and safety of processed fish products in Nigeria

Sub-Activity: Build capacity among women and youth fish processors to produce high quality, safe, and nutritious processed fish products for local consumption

PI: Pasqualino

IEE Condition	Mitigation	Monitoring	Reporting
Category: Education, technical assistance, or training programs. Training and extension activities promoting postharvest loss and fish processing technologies may result in unsustainable use of fish and other natural resources (e.g., fuelwood) if message is poorly conceived and conveyed.	Trainings with fish processors will include recommendations to keep fishing at maximum sustainable yield, although the participants themselves will not be the individuals conducting any fishing activities.	The activity will include a MEL indicator confirming that the activity recommended that fishers not fish above maximum sustainable yields. The activity will monitor the rate at which the fish processors applied/adopted training knowledge and skills to ensure safety of processed fish products, reduce postharvest losses, and improve business expansion and income	This activity ended December 31, 2022. From October to December 2022, the following activities were performed: • Second training of fish processors, December 2022.

Initial environmental examination (IEE) condition		Proposed actions to mitigate risk	How to monitor that mitigation has been undertaken	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
		generation.		

Appendix 5: Climate Risk Screening and Management Report

Defined or anticipated activity elements	Climate risks	How risks are addressed at activity level	Further analysis and actions for activity design/ implementation	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
Integrated rice-fish technology and Lean production for farm management (Nigeria)	Extreme weather events (e.g., storms) could disrupt integrated rice-fish ponds.	Climate risks, such as storms and flooding, must be accepted and mitigated through working with rice growing systems that have the capacity to minimize negative impacts.	Researchers will monitor extreme weather events and implement risk mitigation measures prior to the close of the activity.	Two activities in Nigeria were affected by climate- related shocks in FY22. Three local government areas in Ogun State and two in Delta State were affected by severe flooding, which damaged fishponds and farm inputs and resulted in fish stock loss. Activity teams visited the sites of the floods in both states. Farmers in Delta State were advised to expand the water pathway. Previously reported floods in FY21 and project responses continued into early FY22. The Aquaculture Diversification in Rural Communities activity responded to severe weather events, severe flooding, and severe drought by supporting producers in the use of tube wells to aid pond impoundment and using sandbags to reinforce pond embarkment. The Lean Production Systems activity responded to severe flooding, an exceptionally

Defined or anticipated activity elements	Climate risks	How risks are addressed at activity level	Further analysis and actions for activity design/ implementation	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
				high water table, climate-related storms, and acid rain by providing advice to farmers on the importance of reinforcing pond dikes and guidance on new pond construction to avoid obstructing pathways of surface runoff to flood detention and retention areas.
Insects as aquaculture feed (Nigeria and Malawi)	Natural weather patterns, such as El Niño, hurricanes, floods, droughts, hail, and extreme heat and cold, threaten aquaculture. Slowly changing weather patterns and temperatures can impact the production area of a given standing crop of fish or crops of raw materials for fish feed.	Some stages in raw material crop research for fish feed are amenable to controlled greenhouse research. Other stages require a scaled-up effort in open fields. For research purposes, irrigation can be installed at selected sites to combat drought. Other climate risks, such as flooding, extreme temperatures, hail, etc., must be accepted and mitigated through trials over multiple seasons and at several locations.	No other measures are anticipated.	Nothing to report.
Develop genetic improvements and donor broodstock of IMCs and exotic carps (Bangladesh)	Changes in water body temperatures may impact fish stocks and hence the availability of fish for broodstock.	The broodstock will be developed in 2020, and it is not likely that the risks will occur within the timeframe when the broodstock will be developed. In the long-term, development of a cryogenic sperm bank for carp broodstock will enable climate resilience by allowing selection for temperature tolerance or other environmental stressors.	None	Nothing to report.

Defined or anticipated activity elements	Climate risks	How risks are addressed at activity level	Further analysis and actions for activity design/ implementation	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
Increased understanding of how to manage fish disease risks (Nigeria)	Temperature increases and changes in rainfall patterns have the potential to increase the occurrence of fish disease outbreaks.	All climate risks are accepted because the research aims to understand how to manage disease risks.	None	Nothing to report.
Increased understanding of nutritional value of fish products (Nigeria, Zambia)	Increased nutrition understanding primarily comes from a clinical laboratory setting that is primarily independent of climate.	All climate risks are accepted as they are deemed to be non-impactful to this research area.	None	Nothing to report.
Increased understanding of preferences, needs, and priorities along the fish value chain by gender, age group, or other disadvantaged groups, and application of that understanding to activity design and implementation (Nigeria, Kenya, Bangladesh)	Priorities may be biased during surveys based on current raw material and seasonal needs.	This is an acceptable risk because it still highlights the priorities of producers. Researchers need to be cognizant of the challenges and limitations of this type of research and inherent bias.	Researchers in this field should be fully cognizant of their area of specialty. The research activities will receive technical assistance from the Fish Innovation Lab's resilience technical advisor.	Nothing to report.
Increased and inclusive value-added gains along the value chain, including bottlenecks in innovation adoption and scale-up and where these bottlenecks may be gender-related or affect youth in particular (Nigeria, Bangladesh, Zambia, Cambodia)	Natural weather patterns and slowly changing weather patterns and temperatures can impact the production area of a given standing crop of fish or crops of raw materials for fish feed.	Risks must be addressed on an individual basis.	Researchers will discuss potential climate risks with the resilience technical advisor, using USAID's Climate Risk Screening and Management Framework and adjust research as necessary.	Consultations with regional teams indicate that climate-related changes in weather patterns do not affect fish supply or the availability of raw materials for fish feed for current activities. Severe weather events pose a risk for aquaculture production, specifically in Nigeria as previously addressed in this table.
Improving sustainable fisheries management,	Changes in sea or river temperatures may	Capacity-building efforts and related research on developing sustainable	Researchers will discuss potential climate risks	In Kenya, field enumerators reported reduced fish catch

Defined or anticipated activity elements	Climate risks	How risks are addressed at activity level	Further analysis and actions for activity design/ implementation	Reporting for October 1, 2022, to September 30, 2023, with life of project summary
including shoreline harvesting	impact fish stocks and cause coral bleaching, which could offset gains made by the activity on sustainable fisheries management. Coral may also be impacted by ocean acidification. Extreme weather events, such as storms, can damage coral and cause declines in fish stocks as well as destroy boats used by fishers.	fisheries management activities will consider relevant climate risks.	with the resilience technical advisor, using USAID's Climate Risk Screening and Management Framework and adjust research as necessary.	because of reduced fishing effort linked to the southeast monsoon winds. The activity's post-household survey was more costly and took more time than expected as rain hindered movement by the field team to households.
Human and Institutional Capacity Development (HICD) (Nigeria, Zambia, Kenya, Cambodia, Bangladesh)	Catastrophes due to fire, flood, hurricanes, etc. would interrupt many HICD activities temporarily. Structures that may be depended upon to provide research services could be damaged by climate-related events.	Adaptive management strategies will be used to respond to these unexpected events if necessary.	None	Nothing to report.

Appendix 6. List of Research Datasets

Country	Activity	Dataset name	Description	Data repository link	Note
Nigeria	Aquaculture Diversification in Rural Communities	Resource assessment of integrated fish farming waste products and their apparent digestibility study in the diets of *Oreochromis niloticus* and *Clarias gariepinus*	This study investigated the resources assessment in Kebbi and Ebonyi states. Experimental study was carried out in UI, Aquaculture Nutrition Laboratory to determine the nutrient composition and apparent digestibility coefficient, hematological and serum biochemistry parameters of the test ingredients rice bran feed and fish offal meal feed (procured from USAID/MSU integrated aquaculture-agriculture intervention activity in Nigeria). The estimation of utilizable feed dry matter yield per household farm from rice bran in Kebbi and Ebonyi states were 0.10 and 0.09 t dry matter (ha). Rice bran and fish offal were analyzed for their Amino Acid and Fatty Acid Profiles in each of the samples, Amino Acid content was further evaluated using Provisional Amino Acid of Egg Scoring Pattern to determine their Amino Acid Score.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/SLFX2E&version=DRAFT	Embargoed until September 11, 2024
Nigeria	Aquaculture Diversification in Rural Communities	Integrated rice-fish culture technology adoption, profitability, and food security in Nigeria	Exploring the nexus between food production and consumption through an integrated agriculture-aquaculture program can lead to more production and a sustained farming system. The farming system can potentially support the nutritional needs of vulnerable communities in a sustainable way when properly managed. Explicitly, the system is a form of mutual symbiosis, where both benefit from growing in the same ecosystem. The rice provides the fish with shelter as well as providing shade and, in turn, reduces water temperature, which creates a more suitable environment. Rice plantations decrease the concentrations of ammonia in the water as well as the total of Nitrogen present in the soil, contributing also to improving environmental conditions. Fish also benefit from the herbivorous insects that can be found on the rice by having a supplementary food source. Also, the farmer's income is improved by the integrated rice cultures with an estimated increase of over 23%, and it also benefits the farmer's nutrition requirement and diet by integrating fish protein.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/SKLZVU&version=DRAFT	Embargoed until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Nigeria	Aquaculture Diversification in Rural Communities	Biological productivity and technical efficiency of integrated rice and fish farming for food enhancement in Kebbi and Ebonyi state, Nigeria	For sustainable development of the innovative approach toward raising the productivity of rice and fish production in Ebonyi and Kebbi Nigeria, it is important to document the performance of the two different integrated farming systems examined by analyzing the comparative biological productivity, bioenergetic efficiencies and natural food resources variability in rice-fish farming (African catfish) under the two different ecological arrangements in Nigeria. In this study, the basic biological production processes related to the alternative food chains created through various nutrient flow in the integrated fish and rice farming were examined. In addition, this study identified core influencing factors of technical efficiency to explain the possibilities of increasing productivity and profitability of rice and fish by increasing efficiency at the selected sites in the Kebbi and Ebonyi states. This led to identification of various technical progress policies that would be recommended to help decision-makers increase rice and fish productivity in Nigeria.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/9NIGRT&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Aquaculture Diversification in Rural Communities	Growth performance, immunological responses, and the antioxidant status of *Clarias gariepinus* and *Oreochromis niloticus* Burchell, 1822 fed varying inclusion levels of agro-industrial waste product (rice bran) from integrated fish and rice culture-based diets.	The survival and growth of the fish larvae depend on the quality of feeds used. Quality fish feed production in aquaculture is one of the major determinants of significant growth, efficiency in feed utilization and flesh quality of the fish produced. The expansion of *Oreochromis niloticus* and *Clarias gariepinus* farming is due to their tolerance to a wide range of environmental conditions. Rice bran can be used in fish feed formulation. However, there is limited information on the inclusion of rice bran in the diets of *Clarias gariepinus* and *Oreochromis niloticus*. Hence the need for this study, to investigate the effect of replacement of maize with rice bran on growth and health of the two fish. A 12-week feeding trial was carried out to assess the effect of replacing maize with rice bran in the diets of *Oreochromis niloticus* and *Clarias gariepinus* fingerlings on growth performance, immunological responses, antioxidant status and disease resistance.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PMAFTI&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Nigeria	Aquaculture Diversification in Rural Communities	Growth performance, immunological responses, the antioxidant status of *Clarias gariepinus* and *Oreochromis niloticus* to varying inclusion levels of agro-industrial waste products fish offal meals.	Nigeria, as one of the leading players in African aquaculture, has been tapping the opportunities provided from aquaculture in meeting food and nutrition security needs. In addition, aquaculture serves as a veritable source of employment and livelihood enhancement in Nigeria. With current efforts at intensifying the food production systems in Nigeria for improved livelihood and food and nutrition security, constraints to aquaculture production especially in the area of fish feed development need to be well addressed. It is worthy to note that achieving the highest profit percentage with the lowest cost percentage is critical to the growth of any industry. In the aquaculture industry, the prices of certain feed ingredients are among the major challenges affecting the industry's success or failure. A critical ingredient in aquafeed is fishmeal as it is the costliest and imported in Nigeria. This is due to its highly palatable dietary protein source in aquafeed as it contains balanced amino acids, essential n-3 fatty acids, vitamins, and minerals. Efforts are now tailored towards finding a cost-effective and cheaper local alternative to fishmeal. The fish offal meal, a byproduct of fish processing activities, could be a good alternative to fishmeal. Therefore, there is need to develop a knowledge base on the best ways of utilizing fish offal meal as replacement for fishmeal in diets of two most cultured fish species.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/EVNALS&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Aquaculture Diversification in Rural Communities	Performance evaluation of integrated rice fish farming using Kebbi and Ebonyi states and their adjoining institutional-based platforms as case studies	Options for farm diversification through integrated aquaculture-agriculture are being gradually embraced as a competitive alternative to traditional agriculture because of resource use efficiency and overall productivity. Despite the numerous benefits, the practice of integrated aquaculture-agriculture, especially integrated rice-fish farming in African countries such as Nigeria is limited; therefore, there is a need for proper documentation and demonstration to further encourage integrated rice-fish adoption. This study was carried out on the MSU/USAID/FAO integrated rice-fish plot (22m by 15m) for 16 weeks in two states, which are Ebonyi and Kebbi, and their adjoining institutional-based platforms, which are UI and UDUS, to evaluate the production	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KPTWFS&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			efficiency and to access the water productivity of combining rice-fish. After transplanting rice seedlings and stocking fish seeds, data were collected on the growth and yield performance of fish such as average body weight (g) and length (cm), survival rate (%) and on rice such as number and length of tiller (cm), number and length of panicles (cm), paddy, and grain yield (ton/ha). Water and soil quality parameters such as pH, alkalinity, nitrite, nitrate, ammonia, organic carbon, and nitrogen were collected biweekly and monthly.		
Nigeria	Aquaculture Diversification in Rural Communities	Performance evaluation of integrated rice-fish farming using Kebbi and Ebonyi states and their adjoining institutional-based platforms as case studies	The rice-fish integration system is a means of intensification of crop and fish production with concomitant effects enhancing principles of water conservation, soil improvement, and biological control, and it plays an important role in sustainable production. Fish culture in paddy fields can turn and recycle the available material and energy into fish production, accelerate the productivity of paddy fields and enhance the production potential of traditional farming practice (Caguan et al., 2000) with increased net income (Halwart, 1998).	https://dataverse.harvard.edu/api/access/datafile/7501033	Embargoed Until September 11, 2024
Nigeria	Improving Biosecurity	Microbiology biochems and sensitivity with farmer	Dataset on the microbiology biochemical tests and antimicrobial sensitivity with farmers.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi%3A10.7910%2FDVN%2FQU9ROY&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Improving Biosecurity	Dataset of fish epidemiology and health economics in Ogun and Delta states	Dataset of fish epidemiology and health economics in Ogun and Delta states to understand epidemiology and health economics of catfish and tilapia. The purpose of this dataset was to collect information on catfish production systems, inputs, outputs, health management practices, baseline and abnormal moralities, biosecurity, and health economics in Ogun and Delta states, Nigeria. The uploaded files include cleaned, de-identified datasets in CSV format (multiple individual CSV file for each of the tab in the XLS). Full datasets in XLS format, blank consent form, codebook for the dataset	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/RGG7OW	Published for MSU

Country	Activity	Dataset name	Description	Data repository link	Note
Nigeria	Lean Production Systems	An on-farm performance assessment of aquaculture production systems in Nigeria	The survey was implemented to assess on-farm performance of aquaculture fish production systems in Nigeria. The primary sampling unit was aquaculture farming households/farms. The survey comprised the following modules: (1) farmer characteristics; (2) aquaculture production and marketing activities including input use and cost as well as output harvested and sold; (3) aquaculture experience, change and livelihoods; (4) aquaculture credit and association; (5) food safety and willingness to participate in aquaculture certification. Data on aquaculture production were collected at farm level. The survey captured detailed data about all types of systems and practices allowing for a characterization of farming systems	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/9XLF4O	Published for MSU
Nigeria	Lean Production Systems	Improving efficiency in the Nigerian aquaculture sector by employing Lean production systems. Survey data.	Improving efficiency in the Nigerian aquaculture sector by employing Lean production systems. Survey data.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/O0RLNX&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Harnessing Machine Learning	The structure, conduct, and performance of aquaculture value chain in Bangladesh	The stacked survey technique used for covering representative samples of 1,195 actors from five nodes of the aquaculture value chain in southern Bangladesh. Structured questionnaire was used to conduct survey with 721 aquaculture farmers, 229 fish traders, 100 fish retailers, 79 fish feed traders, and 66 fish hatcheries to assess the structure, conduct, and performance of aquaculture value chain in Bangladesh. (2023-01-27)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/IHKWGE&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Harnessing Machine Learning	The structure, conduct, and performance of aquaculture value chain in Bangladesh	The stacked survey technique was used to conduct survey of large representative samples of 1,195 actors from five nodes of the aquaculture value chain in southern Bangladesh in 2021: fish hatcheries (n=66), feed traders (n=79), aquaculture farms (n=721), and aquatic food wholesalers (n=229) and retailers (n=100). This stacked survey was the second round of a panel first conducted in 2013. In 2021, a new census of respondents was prepared in every area surveyed in 2013. All respondents surveyed in	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LLSNMQ&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			2013 who were identified as still operating in 2021 were resurveyed, and respondents included in the 2013 survey whose businesses had closed, or who were unavailable to participate in the resurvey were replaced at random from the 2021 census list. A structured questionnaire developed in 2013 was modified based on current context, translated into Bangla, and piloted extensively before finalizing. The questionnaire covered four broad topics: 1) Demographic and business characteristics (e.g., volume of working capital, year of establishment), and asset ownership; 2) Procurement and use of aquatic products, labor, credit, and transport; 3) Production technology, product handling, and value addition activities; 4) Marketing behavior. Interviews were conducted face to face by trained enumerators, using tablets. (2023-02-06)		
Bangladesh	Harnessing Machine Learning	The structure, conduct, and performance of aquaculture value chain in Bangladesh	The stacked survey technique was used to conduct survey of large representative samples of 1,195 actors from five nodes of the aquaculture value chain in southern Bangladesh in 2021: fish hatcheries (n=66), feed traders (n=79), aquaculture farms (n=721), and aquatic food wholesalers (n=229) and retailers (n=100). This stacked survey was the second round of a panel first conducted in 2013. In 2021, a new census of respondents was prepared in every area surveyed in 2013. All respondents surveyed in 2013 who were identified as still operating in 2021 were resurveyed, and respondents included in the 2013 survey whose businesses had closed, or who were unavailable to participate in the resurvey were replaced at random from the 2021 census list. A structured questionnaire developed in 2013 was modified based on current context, translated into Bangla, and piloted extensively before finalizing. The questionnaire covered four broad topics: 1) Demographic and business characteristics (e.g., volume of working capital, year of establishment) and asset ownership; 2) Procurement and use of aquatic products, labor, credit, and transport; 3) Production technology, product handling, and value addition activities; 4) Marketing behavior. Interviews	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/5HLK4G&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			were conducted face to face by trained enumerators, using tablets. (2023-02-17)		
Bangladesh	Cryogenic Sperm Banking	Data on catla, silver carp, and bighead carp growth in Bangladesh	Purpose of data collection or generation: 1.) Sperm study data: Fresh, equilibration, and post-thaw motility data of fish sperm were determined to standardize the sperm cryopreservation protocol. 2.) Breeding trial data: Fertilization and hatching rates of eggs were calculated after breeding with cryopreserved sperm to determine the effectiveness of cryopreserved sperm in induced breeding at commercial fish hatcheries of Bangladesh. 3.) Growth study data: Length (cm) and weight (g) data of fish seeds were collected from the experimental ponds of the respected hatcheries to assess the quality of cryopreserved sperm-originated seeds compared to hatchery owned fresh sperm-originated seeds.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/VWVHVE&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Cryogenic Sperm Banking	Fresh, equilibration, and post-thaw motility data of fish sperm data	1.) Sperm study data: Fresh, equilibration, and post-thaw motility data of fish sperm were determined to standardize the sperm cryopreservation protocol. 2.) Breeding trial data: Fertilization and hatching rates of eggs were calculated after breeding with cryopreserved sperm to determine the effectiveness of cryopreserved sperm in induced breeding at commercial fish hatcheries of Bangladesh. 3.) Growth study data: Length (cm) and weight (g) data of fish seeds were collected from the experimental ponds of the respected hatcheries to assess the quality of cryopreserved sperm-originated seeds compared to hatchery owned fresh sperm-originated seeds.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/CWJO0J&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Nourishing Nations	Nourishing Nations Objective 1 Market surveys	Data collected on consumer prices of animal source foods from four market surveys conducted in Delta State, Nigeria.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PKH26K&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Nourishing Nations	Nourishing Nations Objective 1 nutrient and contaminant	Nutrient and contaminant analysis of selected fish samples from Delta State, Nigeria	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DV	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
		analyses of fish samples		N/MZPWYG&version=DRAFT	
Nigeria	Nourishing Nations	Nourishing Nations Objective 3 datasets	Datasets from Objective 3 of the Fish Innovation Lab Nourishing Nations activity in Delta State, Nigeria	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/6PNK4J&version=DRAFT	Embargoed Until September 11, 2024
Zambia	Vaccines for Tilapia	Development and investigation of delivery mode of a multivalent bacterial fish vaccine in Zambia data	The study was initiated by identifying 11 farm owners where their units were segregated as farms. For this activity, the collected information involved the number of farms and fish samples collected. The data was collected from Lake Kariba in Siavonga district (16.5323°S, 28.7111°E) Southern Province of Zambia. The data elaborates the seasonal period of sampling with water parameters at each sampling. The main intention of collecting this data was to collect sick fish and document clinical signs of observed sick fish. The data was generated over a period of 1 year to cover the cold season (July to August), hot season (September to November), and rain season (December to February). Observable clinical signs of disease were used to segregate fish as sick from the identified farms and cages. Infected fish were thoroughly examined and gross lesions such as pale gills, exophthalmia, corneal opacity, abdominal distension, shallow ulcers, skin and fin hemorrhages, and fin erosion were used to target the fish for scooping using a net. The scooped fish were then subjected to analysis and collection of samples. The samples were subjected to bacteria isolation and bacteria identification. The data allowed the team to understand the observed clinical signs and bacteria associated with disease. Data on pathological observations was also interlinked to disease and bacteria isolated. The isolated bacteria were also subjected to antibiotic susceptibility tests to determine the antibiogram profiles of the bacteria found in fish for possible food safety concerns. The limitations with this data would arise from not growing or	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/BEUL7J&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			culturing some bacteria associated with disease as they may not grow on the media used in the study.		
Zambia	Zambia Crayfish	Fish Innovation Lab Zambia Crayfish project	Crayfish Fish Utilization data from surveys and questionnaire	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LLBN5B&version=DRAFT	Embargoed Until September 11, 2024
Zambia	Zambia Crayfish	FGD on crayfish dynamics in Zambia	Focus group discussions (FGDs) were carried out from April 27–28 and June 5–9, 2023 in Sinazongwe (Nzenga fishing village) and Siavonga for Lake Kariba and Itezhi-Tezhi town and Kafue (Chanyanya fishing village) for Kafue River. The themes for discussions were around crayfish dynamics, management, harvest and utilization, and general perspectives on crayfish in Zambia	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/NBKAYO&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Carp Genetic Improvement	WorldFish Carp Genetic Improvement program SNP data obtained using DArTseq in 2021 and 2022	WorldFish Carp Genetic Improvement program, rohu SNP data obtained using DArTseq in 2021 and 2022 during the USAID-funded Feed the Future Fish Innovation Lab (Cooperative Agreement No. 7200AA18CA00030) Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement activity (Subaward 193900.312455.10H). (2023-03-28)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/DRLWR0&version=DRAFT	
Bangladesh	Carp Genetic Improvement	WorldFish Carp Genetic Improvement program families produced in 2021 and 2022	WorldFish Carp Genetic Improvement program, catla, rohu, and silver carp families produced in 2021 and 2022 during the USAID-funded Feed the Future Innovation Lab for Fish (Cooperative Agreement No. 7200AA18CA00030) Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement activity (Subaward 193900.312455.10H). (2023-03-28)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/91BQQO&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Carp Genetic Improvement	WorldFish Carp Genetic Improvement program individuals measured in 2021 and 2022	WorldFish Carp Genetic Improvement program, catla, rohu, and silver carp individuals measured at harvest age in 2021 and 2022 during the USAID-funded Feed the Future Fish Innovation Lab (Cooperative Agreement No. 7200AA18CA00030) Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement activity (Subaward 193900.312455.10H). (2023-03-28) (2023-03-28) (2023-03-28)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/BQHTOH&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Bangladesh	Carp Genetic Improvement	WorldFish Carp Genetic Improvement program individuals transferred to external backup sites in 2021 and 2022	WorldFish Carp Genetic Improvement program, catla, rohu, and silver carp individuals transferred to external backup sites (living gene banks) in 2021 and 2022 during the USAID-funded Feed the Future Fish Innovation Lab (Cooperative Agreement No. 7200AA18CA00030) Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement activity (Subaward 193900.312455.10H). (2023-03-28) (2023-03-28) (2023-03-28)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UTGESS&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Carp Genetic Improvement	WorldFish Carp Genetic Improvement program individuals tagged in 2021 and 2022	WorldFish Carp Genetic Improvement program, catla, rohu and silver carp individuals tagged and placed in ponds for grow out in 2021 and 2022 during the USAID-funded Feed the Future Fish Innovation Lab (Cooperative Agreement No. 7200AA18CA00030) Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement activity (Subaward 193900.312455.10H). (2023-03-28) (2023-03-28)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/GKVZSL&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Carp Genetic Improvement	Assessing potential to implement parentage assignment and communal early rearing in catla	Data to assess potential to implement parentage assignment and communal early rearing in catla. Specifically, • Individuals can accurately and unambiguously be assigned using SNP markers • Pools of two samples from different catla individuals allow accurate and unambiguous parentage assignment • Equal numbers of individuals per family are present at tagging under communal early rearing • The genetic correlation between communal early rearing harvest weight and separate early rearing (SER) harvest weight equals one • Identify and validate putative male-specific (i.e., only present in males) markers for catla and rohu using tissue samples collected as part of routine genetic improvement activities. Tissue samples were collected between October 24, 2022 and November 8, 2022. Genotyping of samples was undertaken in August 2023 in Bangladesh using DArTag	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/QYYXC8&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			(https://www.diversityarrays.com/services/targeted-genotying/). (2023-10-24)		
Nigeria	Farming Insects in Nigeria	The microbial taxonomy profiling was performed using kraken2 against the microbial database	Purpose: Identify potential pathogens from black-soldier-fly-derived compost, which is an important value-added product. • Time Period: June-Aug 2023 • Geographical Coverage: The actual samples were collected in Texas, U.S. But the rearing methods and outputs occur globally. • Methodology: Samples of BSF-derived organic material was obtained from a U.S.-based company. Genomic DNA was extracted according to the manufacturer's protocol using the Qiagen DNeasy Plant Pro Kit. Resulting genomic DNA was used for next-generation sequencing library preparation and sequencing. Libraries were prepared using the Roche Kapa HyperPrep DNA library kit with Kapa Unique Dual-Indexed adapters following manufacturer's recommendations.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/MAEU3F&version=DRAFT	Embargoed Until September 11, 2024
Nigeria	Farming Insects in Nigeria	Baseline and endline surveys' datasets of catfish farmers in Cross River, Ebonyi, and Oyo States, Nigeria	These datasets contain general information about fish farmers in Cross River, Ebonyi, and Oyo States, Nigeria before and after the intervention. (2023-08-13)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/OB7BVP&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Foodborne Pathogens	Identifying major sources of foodborne pathogens in Bangladeshi aquaculture value chains and evaluating the effectiveness of various risk	The database includes the pathogens information found in fish samples tested in the laboratory. In addition, it includes the interview data of fish actors about their hygiene practices.	https://dataverse.harvard.edu/file.xhtml?fileId=7289700&datasetVersionId=348329	Published

Country	Activity	Dataset name	Description	Data repository link	Note
		reduction strategies			
Bangladesh	Market Analysis	N/A	N/A		Used already published secondary data
Kenya	Samaki Salama	Samaki Salama household and child nutrition data	This data contains social, economic, demographic, and environmental data about households participating in the Samaki Salama study. As well, there is nutrition data (anthropometry and dietary intakes) on the index children.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/S7NF4G&version=DRAFT	Embargoed Until September 11, 2024
Kenya	Samaki Salama	Samaki Salama - qualitative data Taita Taveta	This data set contains transcripts from in-depth interviews and focus groups conducted in Taita Taveta.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/ENJT48&version=DRAFT	
Kenya	Samaki Salama	Kenya Samaki Salama fish surveys	Quantitative data from fishing trip surveys collected from the Samaki Salama activity in Kilifi and Taita Taveta Counties from 2021-2022. (2023-05-31)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KASJHB&version=DRAFT	Embargoed Until September 11, 2024
Cambodia	Cambodian Fisheries and Food Processing	Sre Ambel River, Cambodia, fisheries harvest data collected between 2021-2023	Fisheries harvest data from a tropical coastal river in Southeast Asia. Datasets include capture per gear type	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PYCSI3&version=DRAFT	Embargoed Until September 11, 2024
Cambodia	Cambodian Fisheries and Food Processing	Fish sample information	Fish identification and measurement	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/AVBUZ7&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Cambodia	Cambodian Fisheries and Food Processing	Fish dataset Fish Innovation Lab	Data collected on fish breed sampled	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/2W0MEIandversion=DRAFT	Embargoed Until September 11, 2024
Cambodia	Cambodian Fisheries and Food Processing	Fish preservation, processing, and nutritional knowledge data	1) Survey data: A series of questions was designed to solicit information on fish preservation, processing, and nutritional knowledge. 2) Sensory data: Three fish species were selected for sensory evaluation including strip snakehead (*Channa striata*), walking catfish (*Clarias batrachus*), striped catfish (*Pangasius djambal*), and fermented striped catfish. 3) Nutritional data: Eleven fish species were collected for proximate and fatty acid analysis for this study including, *Channa striata, Channa lucius, Hemibagrus filamentus, Barbonymus gonionoyus, Larbiobarbus siamensis, Puntioplites bulu, Channa micropites,* and *Oxyeleotris marmorata* were collected from Sre Ambel River. 4) Shelf life data: Forty-five catfish fillets were obtained for three replications of five antimicrobial treatments (25.5% of buffer dried vinegar, 25.5% rosemary extract, 12.5% combination of buffer dried vinegar and rosemary extract, positive control, and negative control). 5) Training and continuation assessment data: The team conducted two workshops to train fishers in fresh fish processing and preservation.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/YSAJIS&version=DRAFT	Embargoed Until September 11, 2024
Cambodia	Bighead Catfish	The experiment aimed to evaluate some of the commercially available feed for bighead catfish culture	The experiment in the wet lab was conducted for 12 weeks from January 31–April 26, 2023 3.) Geographical Coverage: The experiment was conducted in a wet lab located at the aquaculture farm of faculty of fisheries and aquaculture, Royal University of Agriculture in Cambodia. 4.) Methodology: All fish were weekly removed from aquarium for weighing, length measurement, and final sampling (dissected to collect gonad, liver, and viscera). The fillet fish were submitted to 58 panelists for appearance, dour, flavor, consistency, and preference evaluation. Dissolved oxygen, pH, and temperature were measured daily. pH was measured by Eco-Sense pH 10A parameter. Dissolved oxygen and temperature were measured by Eco-Sense D.O	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/362EIJ&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
			200A. TAN (total ammonia nitrogen), NO2- (nitrite), NO3- (nitrate), hardness, and alkalinity were measured weekly by sera test kit with water drops to compare the color. (2023-09-11)		
Kenya	Coral Reef Fishery Sustainability	Fish landing data	The dataset contains fish catch sampling sites and respective management type, fishing effort, total catch per landing and weightings per fishing groups, and prices per fishing group sampled between 2021-2023. Geographic location of data collection: Mkwiro, Wasini, Shimoni, Kibuyuni, Majoreni, Vanga, and Jimbo.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KKCHUV&version=DRAFT	Embargoed Until September 11, 2024
Kenya	Coral Reef Fishery Sustainability	Effort and fisheries laws and household surveys	The study hypothesized that compliance of fisheries laws for the benefit of resource users and environment will depend on knowledge, acceptance, and enforcement of the said laws. The questionnaire targeted primary resource users, mostly fisher fork that included men and women. The pre-data survey was to understand the perceptions on governance and agreement for fisheries restrictions before and during the activity. The questionnaire had sub-themes as follows; 1) Demographics, 2) Fish resource dependency and fish consumption, 3) Perceived benefits of fisheries restrictions, 4) Strength of governance institutions. The post-data data was collected after the activity period. The survey was to understand the changes in perceptions on governance and agreement for fisheries restrictions before and during the activity. The questionnaire had sub-themes as follows; 1) Demographics, 2) Fish resource dependency and fish consumption, 3) Perceived benefits of fisheries restrictions, 4) Strength of governance institutions.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/NVG2KM&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Zambia	FishFirst! Zambia	Research for development and scaling staple-fish products for enhanced nutrition in the first 1,000 days of life	Supported by USAID through the Feed the Future Innovation Lab for Fish, FishFirst! Zambia is a joint initiative of researchers at MSU and WorldFish (which leads the CGIAR initiative on Aquatic Foods). FishFirst! Zambia is focused on research for developing and scaling staple-fish products for enhanced nutrition in the first 1,000 days of life (from conception until age 2 years). FishFirst! Zambia's goal is to increase the quality and quantity of fish benefitting nutrition and food security in Zambia, particularly for infants and young children in the first 1,000 days of life (from conception until age 2 years) and for pregnant and breastfeeding women. A primary outcome of FishFirst! Zambia was development of a novel locally sourced, high-quality dried fish-based protein/micronutrient blend, Complementary Food for Africa+Dried Fish Powder (ComFA+Fish).	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/IXNFDQ&version=DRAFT	Embargoed Until September 11, 2024
Zambia	FishFirst! Zambia	ComFA+Fish taste-test ii	This research study aims to conduct a taste test among mothers, entrepreneurs, and government representatives to learn whether they find ComFA+Fish instant porridge tasty and acceptable. The instant porridge tasted in this study is made of fish powder, millet, and powder from baobab fruit. (2023-07-18)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/XEIOEZ&version=DRAFT	Embargoed Until September 11, 2024
Zambia	FishFirst! Zambia	Data set Fish First Zambia taste-tests	The purpose of this research study is to conduct a taste-test among mothers and their infants to learn whether they find a food tasty and acceptable. This food is called Complementary Food for Africa+Dried Fish Powder (ComFA+Fish). It is added to traditional maize porridge to increase its nutrition for infants and young children. The ingredients of ComFA+ are locally sourced dried fish powder, groundnut powder, orange-fleshed sweet potato, and vegetable oil, cooked in water. The team conducted a taste-test among mothers (18-49 years) and their infants (6-23 months) of traditional maize porridge to which ComFA+ had been added.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/64EVHH&version=DRAFT	Embargoed Until September 11, 2024

Country	Activity	Dataset name	Description	Data repository link	Note
Zambia	FishFirst! Zambia	Focus group discussion on complementary food for Africa+Dried Fish Powder (ComFA+Fish)	This qualitative data is based on a three-focus group discussion on ComFA+Fish. The purpose of the FGDs was to gather feedback from diverse stakeholders on the use of dried fish powder for child and household nutrition in Zambia's Lake Kariba region. Participants were drawn from three southern districts in Zambia including, Gwembe (6), Siavonga (16) and Sinazongwe (6). Participants were categorized into three groups: Government Agents; Women, Mothers & Caregiver's; and Entrepreneurs. All participants provided consent at the beginning of the discussion and no identifier information was collected.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KIER8V&version=DRAFT	Embargoed Until September 11, 2024
Ghana	Micronutrient Impact of Oysters	Micronutrient impact of oysters in the diet of women shellfishers	The objective of this research was to determine the mineral and heavy metal content of 915 oysters from three oyster estuarine sites in Ghana and how they contribute to the total iron and zinc intake of women shellfishers. (2023-03-22)	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/JGDTAU&version=DRAFT	Embargoed Until September 11, 2024
Bangladesh	Genome Sequencing [Quick Start]	1. Genome sequence data: raw data resides on sequence read archive (SRA) (accessions srr12580210–srr12580221).	For each Nanopore sequencing run, 2 to 2.5 g of genomic DNA was used in the library preparation with Nanopore Genomic DNA Ligation Sequencing Kit SQK-LSK 109 (Oxford Nanopore Technologies, Oxford, UK). The final library (about 700 to 750 ng) was loaded on a Nanopore Flow Cell R9.4.1 (Oxford Nanopore Technologies, Oxford, UK) and sequenced on GridION sequencer (Oxford Nanopore Technologies, Oxford, UK) for 48 hours. A total of 10 flow cell runs were conducted for the genome assembly.	https://www.ncbi.nlm.nih.gov/sra/?term=SRR12580210	Repository on SRA of the National Library of Medicine https://www.ncbi.nlm.nih.gov/sra
Bangladesh	Genome Sequencing [Quick Start]	2. SNP discovery: raw data resides on SRA (accessions srr19358298–srr19358417).	DNA was extracted from fins using Qiagen DNeasy Blood and Tissue Mini kits (Qiagen, Valencia, CA, USA). Libraries were made using the method described in Magbanua et al. (2022) using NsiI and MspI (New England Biolabs (NEB), Ipswich, MA) restriction enzymes. The libraries were submitted to Novogene (www.en.novogene.com) for sequencing.	https://www.ncbi.nlm.nih.gov/sra/?term=SRR19358298 https://github.com/IGBB/rohu-genome	Respository on SRA of the National Library of Medicine https://www.ncbi.nlm.nih.gov/sra

Country	Activity	Dataset name	Description	Data repository link	Note
Kenya	SecureFish [Quick Start]	Data on the social and economic contribution fisheries provide for coastal communities in Kenya	This data was collected to determine the social and economic contribution fisheries provide for coastal communities in Kenya. The data was collected from July to September 2019. The data covers areas from Shimoni (04°48′38″S 39°22′59″E), Tiwi (4°15′10″S 39°35′31″E), Vipingo (3° 48' 28"S 39° 49' 54" E), Uyombo (3° 23' 40" S 39° 58' 2" E). Fishers were asked their consent in the study and surveys were conducted at fish landing sites or within homes using pen and paper.	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi%3A10.7910%2FDVN%2FSSIN5E&version=DRAFT	
Nigeria	Cold Chain Analysis [Quick Start]	An on-farm performance assessment of aquaculture production systems in Nigeria	The survey was implemented to assess on-farm performance of aquaculture fish production systems in Nigeria. The primary sampling unit was aquaculture farming households/farms. The survey comprised the following modules: 1) farmer characteristics; 2) aquaculture production and marketing activities including input use and cost as well as output harvested and sold; 3) aquaculture experience, change, and livelihoods; 4) aquaculture credit and association; 5) food safety and willingness to participate in aquaculture certification. Data on aquaculture production were collected at farm level. The survey captured detailed data about all types of systems and practices allowing for a characterization of farming systems	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/9XLF4O	

Appendix 7. List of Publications and Presentations

No.	Year	Country	Type	Activity name	Citation
1	2023	Nigeria	Publication	Nourishing Nations	Adegoye, Grace Adeola, Terezie Tolar-Peterson, Henrietta Nkechi Ene-Obong, Joseph Nkem Nuntah, Monica M. Pasqualino, Rahel Mathews, Juan L. Silva, Wen-Hsing Cheng, Marion Willard Evans, Jr., and Lauren Pincus. 2023. "Development and Validation of Nutrition and Food Safety Educational Material for Fish Processors in Nigeria." International Journal of Environmental Research and Public Health 20, no. 6: 4891. https://doi.org/10.3390/ijerph20064891.
2	2023	Nigeria	Presentation	Improving Biosecurity	Alarape, S. A. "Isolation and Characterization of Klebsiella and Pseudomonas Species From Farmed African Catfish in Nigeria and Their Implications." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
3	2023	Bangladesh	Publication	Harnessing Machine Learning	Ali, Hazrat, Ben Belton, Mohammad Mahfujul Haque, and Khondker Murshed-e-Jahan. "Transformation of the Feed Supply Segment of the Aquaculture Value Chain in Bangladesh." Aquaculture 576 (July 2023): 739897. https://doi.org/10.1016/j.aquaculture.2023.739897.
4	2023	Bangladesh	Publication	Harnessing Machine Learning	Ali, Hazrat, Ben Belton, Mohammad Mahfujul Haque, Khondker Murshed-e-Jahan, and Liz Ignowski. "The Structure, Conduct, and Performance of the Hatchery Segment of the Aquaculture Value Chain in Bangladesh." Frontiers in Aquaculture 2 (July 2023). https://doi.org/10.3389/faquc.2023.1219458.
5	2023	Bangladesh	Presentation	Foodborne Pathogens	Amin, M. B., Islam, M. A., Narrod, C., Parveen, S., Hoque, K. I., Sraboni, A. S., & Uddin, H. "Assessment of Foodborne Pathogens and Hygiene Practices Along the Fish Supply Chains in Bangladesh." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
6	2023	Bangladesh	Presentation	Cryogenic Sperm Banking	Azmi, A. M. "Standardization of Cryopreservation Protocol of Indian Major Carp, Mrigal (*Cirrhinus cirrhosus*) and Production of Seeds Using Cryopreserved Sperm in Selected Hatcheries." Thesis presentation, Department of Fisheries Biology and Genetics, Bangladesh Agricultural University, Mymensingh, Bangladesh, March 2023.
7	2023	Cambodia	Presentation	Cambodian Fisheries and Food Processing	Chum, C., Wang, S., Dahlgren, C., Som, S., Schilling, M.W., Allen, P.J., Neal, J.W., Correa, S., and Dinh, T. "Consumer Preference for Fish Species and Cooking in Cambodia." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
8	2023	Kenya	Publication	N/A	Cohn, Rachel M., Ruth Mbeyu, Catherine Sarange, Francis Mbogholi, Christopher Cheupe, Joaquim Cheupe, Andrew Wamukota, Elizabeth Kamau, and Melva Treviño. "Carrier Bag Storytelling with Coastal Kenyan Families: Sharing Food, Illustrations, and Knowledge for Tangible Environmental Justice Impacts." Frontiers in Communication 8 (2023). https://doi.org/10.3389/fcomm.2023.1173512.

No.	Year	Country	Type	Activity name	Citation
9	2023	Cambodia	Presentation	Cambodian Fisheries and Food Processing	Correa, S., Neal, J. W., Allen, P. J., Som, S., and Yon, T.G. "iFISH - A Citizens-Science-Based Community Fisheries Assessment Tool." Annual Meeting, American Fisheries Society, Grand Rapids, MI, August 2023.
10	2023	Bangladesh	Presentation	Market Analysis	Dey, M., Hossain, M., Rahman, M. T., and Khan, M. "How Price and Non-Price Factors Influence the Market Price of Major Carp Fish: An Advanced Time Series Analysis." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
11	2023	Bangladesh	Presentation	Market Analysis	Dey, M., Hossain, M., Rahman, M. T., and Khan, M. A. "Export Potentiality of Aquaculture Fish Species: Evidence From Bangladesh." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
12	2023	Bangladesh	Presentation	Market Analysis	Dey, M., Rahman, M. T., Das, A., Deb, P., and Khan, M. "Household Fish Consumption Pattern in Bangladesh." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
13	2023	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. "Can the Diversification of Rice Farming With Fish Support Communities and Countries in Achieving the Sustainable Development Goals? Insights From Nigeria, Lao PDR, and P.R. China." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
14	2023	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Fonsah, E. G. "Apparent Digestibility Coefficients of By-Products in Integrated Rice and Fish Farming (Rice Bran and Fish Offal Meal) Fed to the African Catfish Clarias gariepinus (Burchell, 1822) and Oreochromis niloticus (Linnaeus, 1758) Juveniles." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
15	2023	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Fonsah, E. G. "Assessment of Water Utilization, Water Quality Performance, and Nutrient Requirement Under Integrated Rice-Fish Farming." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
16	2023	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Fonsah, E. G. "Maximizing the Nutritional Impact of a Farm Diversification (Rice-Fish) Intervention: A Case Study From Nigeria." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
17	2023	Bangladesh	Presentation	Carp Genetic Improvement	Hamilton, M.G., Yeasin, M., Akhter, M.M., and Benzie, J.A.H. "Genetic Improvement of Rohu (*Labeo rohita*) in Bangladesh." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.

No.	Year	Country	Type	Activity name	Citation
18	2023	Nigeria	Presentation	Improving Biosecurity	Hanson, L. A. "Understanding Aquaculture Biosecurity to Improve Catfish Disease Management in Ogun and Delta States, Nigeria." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
19	2023	Zambia	Presentation	Fish First! Zambia	Howard, D., Read-Wahidi, and M., Ragsdale, K. 2023. "Why is Gender Equity Important in Agricultural Development? Assessing Gender Responsive Research in the Feed the Future Innovation Lab for Fish." Poster Presentation, Mississippi State University Undergraduate Research Symposium, Mississippi State, MS, April 13-14, 2023.
20	2023	Bangladesh	Presentation	ME	Hussain, Gulam. “Aquaculture in Bangladesh: Recent Advancement, Prospects, Challenges and Overall Impacts of Fish Innovation Lab Funded Projects.” Presentation, Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
21	2023	Bangladesh	Publication	N/A	Hussain, M. Gulam, M.S. Islam, M. Moshiur Rahman, and A.H.M. Kohinoor. “Genetically Improved Aquaculture Species in Bangladesh.” Frontiers in Aquaculture Biotechnology, 25–46, 2023. https://doi.org/10.1016/B978-0-323-91240-2.00001-4.
22	2023	Bangladesh	Publication	Harnessing Machine Learning	Ignowski, L., Belton, B., Ali, H. et al. 2023. "Integrated Aquatic and Terrestrial Food Production Enhances Micronutrient and Economic Productivity for Nutrition-Sensitive Food Systems." Nature Food. https://doi.org/10.1038/s43016-023-00840-8.
23	2023	Kenya	Publication	Samaki Salama	Kamau-Mbuthia, Elizabeth, Carolyn Lesorogol, Andrew Wamukota, Austin Humphries, Catherine Sarange, Ruth Mbeyu, Chris Cheupe, et al. “Sustainable Aquatic Food Systems: Multisectoral Analysis of Determinants of Child Nutrition in Coastal Kenya.” Frontiers in Sustainable Food Systems 7 (2023). https://doi.org/10.3389/fsufs.2023.1091339.
24	2023	Bangladesh	Presentation	Market Analysis	Khan, M., Rahman, M. T., DEY, M. M., and Islam, I. "Are Trade Credits a Drain for Gain in the Aquaculture Industry of Bangladesh?" Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
25	2023	Zambia	Presentation	Fish First! Zambia	Kolbila, R., Ragsdale, K., Mudege, N.M., Read-Wahidi, M.R., Muzungaire, L., and Kakwasha, K. "FishFirst! Zambia: Sensory Panel III Results for Two Novel ComFA+Fish Instant Complementary Porridges and Implications for Scaling Across Zambia and Sub-Saharan Africa." Mississippi Academy of Sciences and Mississippi State University: 2023 Summer Science & Engineering Symposium, Mississippi State University, MS, July 2023.
26	2023	N/A	Presentation	ME	Lawrence, M., Allen, P. "Fish to feed the world: Advancing sustainable solutions for global food security." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.

No.	Year	Country	Type	Activity name	Citation
27	2023	Kenya	Presentation	Coral Reef Fishery Sustainability	McClanahan, T. R., Kosgei, J. K., Oddenyo, R., Abunge, C., & Kodi, M. A. "Challenges to Rural and Fisheries Planning and Development on the Kenya-Tanzania International Boundary." The 12th WIOMSA Scientific Symposium, Port Elizabeth, South Africa, July 2023.
28	2023	Bangladesh	Publication	Market Analysis	Md. Akhtaruzzaman Khan, Md. Emran Hossain, Md. Takibur Rahman, and Madan Mohan Dey. 2023. "COVID-19's effects and adaptation strategies in fisheries and aquaculture sector: An empirical evidence from Bangladesh." Aquaculture 562, (January 2023). 738822, ISSN 0044-8486. https://doi.org/10.1016/j.aquaculture.2022.738822.
29	2023	Bangladesh	Presentation	Market Analysis	Mim, J. M. and Khan, M. "Access to Credit and Trade Credit in Aquaculture Farming of Bangladesh." Thesis presentation, Bangladesh Agricultural University, Bangladesh, March 2023.
30	2023	Ghana	Presentation	Micronutrient Impact of Oysters	Oaks, B. "Anemia, Food Insecurity, and Oyster Consumption Among Women Shellfishers in Ghana and the Gambia." International Congress of Nutrition, Tokyo, Japan, December 2022.
31	2023	Zambia	Presentation	Fish First! Zambia	Ragsdale, K., Read-Wahidi, M., Mudege, N., Marinda, P., and Kolbila, R. 2023. "Using a Gender Lens to Explore Food Insecurity among Rural Fishers, Processors, and Fish Traders at Zambia's Lake Kariba: Results from the Household Hunger Scale II." Accepted Oral Presentation, Nutrition 2023 Conference, American Society for Nutrition, Boston, MA, July 22-25, 2023.
32	2023	Bangladesh	Presentation	Cryogenic Sperm Banking	Sarder, M.R.I., Rahman, M.M., Mariom, Alam, M.J., Razzak, M.A., Hossian, S. and Tiersch, T.R. "Cryogenic Sperm Banking of Catla (*Catla catla*), Bighead Carp (*Hypophthalmichthys nobilis*), and Grass Carp (*Ctenopharyngodon idella*) and Production of Seeds in Commercial Hatcheries." Aquaculture America 2023 Conference, New Orleans Marriott Hotel, New Orleans, Louisiana, U.S.A., February 2023.
33	2023	Zambia	Presentation	Fish First! Zambia	Sawyer, N., Ragsdale, K., Mudege, N., Read-Wahidi, M., Marinda, P., Muzungaile, L. Kakwasha, K., and Kolbila, R. 2023. "Adapting the Household Hunger Scale to Collect Food Insecurity Data at Both the Individual- and Household-Level at Zambia's Lake Kariba." Poster Presentation, Mississippi State University Undergraduate Research Symposium, Mississippi State, MS, April 13-14, 2023.
34	2023	Zambia	Publication	Vaccines for Tilapia	Siamujompa, Mazuba, Kunda Ndashe, Frederick Chitonga Zulu, Chanda Chitala, Mwansa M. Songe, Katendi Changula, Ladslav Moonga, Emmanuel Shamulai Kabwali, Stephen Reichley, and Bernard Mudenda Hang'ombe. 2023. "An Investigation of Bacterial Pathogens Associated with Diseased Nile Tilapia in Small-Scale Cage Culture Farms on Lake Kariba, Siavonga, Zambia." Fishes 8, no. 9: 452. https://doi.org/10.3390/fishes8090452.

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35	2023	Zambia	Presentation	Fish First! Zambia	Smith, M., Ragsdale, K., Mudege, N.M., Read-Wahidi, M.R., Muzungaire, L., Iannotti, L., Kolbila, R., and Kakwasha, K. "FishFirst! Zambia: Engaging Private Sector Actors in Scaling ComFA+Fish Protein/Micronutrient Blends and Testing Four ComFA+Fish-Fortified Traditional Dishes and Two Instant Complementary Porridges." Poster presentation, Mississippi State University: 2023 Summer Undergraduate Research Symposium, Mississippi State University, MS, August 2023.
36	2023	Zambia	Presentation	Fish First! Zambia	Smith, M., Ragsdale, K., Mudege, N.M., Read-Wahidi, M.R., Muzungaire, L., Kolbila, R., and Kakwasha, K. "FishFirst! Zambia Sensory Panels I-II: Evaluating Four ComFA+Fish-Fortified Traditional Dishes Among Zambian Mothers and Infants." Mississippi Academy of Sciences and Mississippi State University: 2023 Summer Science & Engineering Symposium, Mississippi State University, MS, July 2023.
37	2023	Zambia	Presentation	Fish First! Zambia	Smith, M., Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaile, L., Funduluka, P., Muzungaile, T., Kakwasha, K., and Kolbila, R. 2023. "FishFirst! Zambia Nutrition-Related Activities: Encouraging Fish Consumption Among Vulnerable Mother-Infant Dyads at Lake Kariba." Poster Presentation, Mississippi State University 2023 Undergraduate Research Symposium, Mississippi State, MS, April 13-14, 2023.
38	2023	Cambodia	Presentation	Cambodian Fisheries and Food Processing	Yon, T. "Assessing Spatial and Seasonal Patterns of Fish Diversity of Artisanal Fisheries in the Sre Ambel River System." Thesis presentation, Royal University of Phnom Penh, Cambodia, February 2023.
39	2023	Bangladesh	Presentation	Market Analysis	Zaman, H. and Khan, M. "Impact of COVID-19 on Aquaculture Farming in Bangladesh." Thesis presentation, Bangladesh Agricultural University, Bangladesh, March 2023.
40	2022	Singapore	Presentation	ME	Reichley, S. R., Allen, P., Iannotti, L., Ragsdale, K., Read-Wahidi, M., Ricci, G., Springer, J., Torell, E., Lawrence, M. L. "The Feed the Future Innovation Lab for Fish: Achieving Security Through Blue Foods". World Aquaculture Singapore 2022, Singapore, December 2022.
41	2022	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Fonsah, E. G. "Economic and Health Benefits of Introducing Fish in Rice Producing Farms of Nigeria." World Aquaculture Singapore 2022, Singapore, December 2022.
42	2022	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Fonsah, E. G. "Lessons From Introduction of Integrated Rice-Fish System in Northern and Southern Regions of Nigeria." World Aquaculture Singapore 2022, Singapore, December 2022.
43	2022	South Africa	Presentation	ME	Reichley, S. R. and Lawrence, M. L. "The Feed the Future Innovation Lab for Fish: Achieving Security Through Blue Foods". World Aquatic Health Conference 2022, South Africa, December 2022.

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44	2022	Kenya	Publication	Coral Reef Fishery Sustainability	Galligan, Bryan P., McClanahan, Timothy R., and Humphries, Austin T. 2022. "Nutrient Capture and Sustainable Yield Maximized by a Gear Modification in Artisanal Fishing Traps." Environmental Research Letters 17, no. 124035. https://iopscience.iop.org/article/10.1088/1748-9326/aca77e/meta.
45	2022	Kenya	Publication	Samaki Salama	Blackmore, Ivy, Andrew Wamukota, Elizabeth Kamau-Mbuthia, Austin Humphries, Carolyn Lesorogol, Rachel Cohn, Catherine Sarange, et al. “Samaki Salama – Promoting Healthy Child Growth and Sustainable Fisheries in Coastal Kenya: A Study Protocol.” Frontiers in Public Health 10 (2022). https://doi.org/10.3389/fpubh.2022.934806.
46	2022	Kenya	Publication	Samaki Salama	Cartmill, M. K., Blackmore, I., Sarange, C., Mbeyu, R., Cheupe, C., Cheupe, J., Kamau-Mbuthia, E., Iannotti, L., Wamukota, A., Humphries, A., & Lesorogol, C. 2022. "Fish and complementary feeding practices for young children: Qualitative research findings from coastal Kenya." PLoS ONE, 17(3), e0265310. https://doi.org/10.1371/journal.pone.0265310.
47	2022	Zambia	Presentation	Fish First! Zambia	Chisopo, A., Marinda, P., Mudege, N., Read-Wahidi, M., Ragsdale, K., Kolbila, R., & Smith, M. 2022. "Post-harvest fish loss and impacts on smallscale fishery livelihoods in Zambia and adjacent countries: A FishFirst! Zambia literature review." Poster Presentation, 2022 Spring Undergraduate Research Symposium, Mississippi State University, MS. April 13, 2022.
48	2022	Bangladesh	Publication	Market Analysis	Deb, P., Dey, M. M., Surathkal, P. 2022. "Fish price volatility dynamics in Bangladesh." Aquaculture Economics & Management. https://doi.org/10.1080/13657305.2021.2008049.
49	2022	Bangladesh	Publication	Carp Genetic Improvement	Hamilton, M., Yeasin, M., Alam, M., Ali, M., Fakhruddin, M., Islam, M., Barman, B., Shikuku, K., Shelley, C., Rossignoli, C., and Benzie, J. 2022. "On-farm performance of genetically-improved rohu (*Labeo rohita*) in Bangladesh." Frontiers in Aquaculture 1. https://doi.org/10.3389/faquc.2022.1060335.
50	2022	Bangladesh	Publication	Genome sequencing (QS)	Hossain, M. E., Khan, M. A., Dey, M. M., and Alam, M. S. 2022. "Insights of freshwater carp polyculture in Bangladesh: Inefficiency, yield gap, and yield loss perspectives." Aquaculture, 557. https://doi.org/10.1016/j.aquaculture.2022.738341.
51	2022	Bangladesh	Publication	Genome sequencing (QS)	Hossain, M. E., Khan, M. A., Saha, S. M., and Dey, M. M. 2022. "Economic assessment of freshwater carp polyculture in Bangladesh: Profit sensitivity, economies of scale and liquidity." Aquaculture, 548(1). https://doi.org/10.1016/j.aquaculture.2021.737552.

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52	2022	Bangladesh	Publication	N/A	Hussain, M.G., Islam, M.S., Rahman, M.M., and Kohinoor, A.H.M. 2022. "Genetically Improved Aquaculture Species in Bangladesh: Advances and Challenges." In: W.S. Lakra, M. Goswami and V.L. Trudeau (Editors), Frontiers in Aquaculture Biotechnology, pp 25 – 45, Elsevier, Academic Press, 125 London, United Kingdom. http://dx.doi.org/10.1016/B978-0-323-91240-2.00001-4.
53	2022	Bangladesh	Publication	N/A	Hussain. M. G. 2022. "Threatened Fish Genetic Resources and Biological Diversity of the Baluhar Baor Wetland in Bangladesh." Journal of Bangladesh Agriculture, 11(1), 47-56.
54	2022	N/A	Presentation	N/A	Iannotti, L.L., Oaks, B.M., Ragsdale, K., and Tolar-Peterson, T. "Role of Fish and Other Aquatic Animal-Source Food in Enhancing Nutrition and Food Security Among Vulnerable Populations in Sub-Saharan Africa: Evidence from Ghana, Kenya, Nigeria, and Zambia." Panel presentation, American Public Health Association Annual Meeting, Boston, MA, November 2022.
55	2022	Bangladesh	Publication	Harnessing Machine Learning	J. Sebastian Hernandez-Suarez, A. Pouyan Nejadhashemi, Hannah Ferriby, Nathan Moore, Ben Belton, and Mohammad Mahfujul Haque. 2022. "Performance of Sentinel-1 and 2 imagery in detecting aquaculture waterbodies in Bangladesh." Environmental Modelling & Software 157, 105534, ISSN 1364-8152. https://doi.org/10.1016/j.envsoft.2022.105534.
56	2022	Zambia	Presentation	Fish First! Zambia	Malama, F., Marinda, P., Mudege, N., Read-Wahidi, M., Ragsdale, K., Kolbila, R., and Issac, A. 2022. "Fish consumption and related nutritional status among women and young children in Zambia and adjacent countries: A FishFirst! Zambia literature review." Poster Presentation, 2022 Spring Undergraduate Research Symposium, Mississippi State University, MS, April 13, 2022.
57	2022	Bangladesh	Publication	Genome sequencing (QS)	Mark A. Arick II, Corrinne E. Grover, Chuan-Yu Hsu, Zenaida Magbanua, OlgaPechanova, Emma R. Miller, Adam Thrash, Ramey C. Youngblood, Lauren Ezzell, Md Samsul Alam, John A. H. Benzie, Matthew G. Hamilton, Attila Karsi, Mark L. Lawrence, and Daniel G. Peterson. 2022. "A high-quality chromosome-level genome assembly of rohu carp, Labeo rohita, and its utilization in SNP-based exploration of gene flow and sex determination." bioRxiv. 10.1093/g3journal/jkad009. http://dx.doi.org/10.1093/g3journal/jkad009.
58	2022	Bangladesh	Publication	Market Analysis	Md. Akhtaruzzaman Khan, Md. Emran Hossain, Md. Sayemul Islam, Md. Takibur Rahman, and Madan Mohan Dey. 2022. "Shrimp export competitiveness and its determinants: A novel dynamic ARDL simulations approach." Aquaculture Economics & Management 27, no. 2 (June 24, 2022): 221-248. https://doi.org/10.1080/13657305.2022.2089772.

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59	2022	Nigeria	Presentation	Farming Insects in Nigeria	Omonona, B. T. "Fish Feed Production Using Black Soldier Fly Larvae as Replacement for Fish Meal." FAO National Workshop on Rice-Fish Farming: A Farm Diversification Strategy, Ibadan, Nigeria, December 2022.
60	2022	Zambia	Publication	Fish4Zambia (QS)	Ragsdale, K., Read-Wahidi, M. R., Marinda, P., Pincus, L., Torell, E., and Kolbila, R. 2022. "Adapting the WEAI to explore gender equity among fishers, processors, and sellers/traders at Zambia's Lake Bangweulu." World Development 152, 105821. https://doi.org/10.1016/j.worlddev.2022.105821.
61	2022	Bangladesh	Presentation	Cryogenic Sperm Banking	Rahman, M.M., Razzak, M.A., Sarder, M.R.I., Mariom, and Tiersch, T.R. "Development of Cryogenic Sperm Bank of Silver Carp (*Hypophthalmichthys molitrix*) and Seed Production in Commercial Hatcheries for Brood Banking." World Aquaculture Singapore 2022, Singapore, December 2022.
62	2022	Bangladesh	Presentation	Cryogenic Sperm Banking	Sarder, M.R.I., Alam, M.J., Rahman, M.M., Mariom, and Tiersch, T.R. "Cryogenic Sperm Banking of Indian Major Carp, Rohu (*Labeo rohita*), and Production of Quality Seeds in Commercial Hatcheries." World Aquaculture Singapore 2022, Singapore, December 2022.
63	2022	N/A	Publication	N/A	Zhang, W., Belton, B., Edwards, P. Henrikkson, P. J. G., Little, D. C., Newton, R., and Troell, M. 2022. "Aquaculture will continue to depend more on land than sea." Nature 603, E2-E4. https://doi.org/10.1038/s41586-020-2616-y.
64	2021	N/A	Publication	N/A	Barría, A., Trịnh, T. Q., Mahmuddin, M., Peñaloza, C., Papadopoulou, A., Gervais, O., Chadag, V. M., Benzie, J. A. H., and Houston, R. D. 2021. "A major quantitative trait locus affecting resistance to Tilapia lake virus in farmed Nile tilapia (*Oreochromis niloticus*)." Heredity 127, (July 2021): 334–343. https://doi.org/10.1038/s41437-021-00447-4.
65	2021	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Burtle, Gary J. "Feeding Fish in Rice-Fish Systems." University of Ibadan Seminar, Ibadan, Nigeria, August 2021.
66	2021	N/A	Presentation	ME	Colverson, K., Ragsdale, K., Castellanos, P., Sumner, D., O'Brien, C., Read-Wahidi, M. R., Tufan, H. A., and Marter-Kenyon, J. 2021. "Gender across USAID's Feed the Future Innovation Labs: Lessons and approaches that cultivate gender-transformative agricultural development." Panel Session, Cultivating Equality Conference 2021: Advancing Gender Research in Agriculture and Food Systems, Virtual.
67	2021	Bangladesh	Publication	N/A	Failler, P., Hussain, M. G., Karim, A. A., Alam, M. K, Sarker, S., Rouf, M. A., Sharifuzzaman, S. M., Hossain, M. M., Nobi, M. N., Das, J., Uddin, S. A., Shemon, W. S., and Hassan, D. 2021. "The future of the blue economy in Bangladesh." Bangladesh Maritime Journal, Special Issue, 15 - 28.

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68	2021	Bangladesh	Publication	Harnessing Machine Learning	Ferriby H., Nejadhashemi A. P., Hernandez-Suarez J. S., Moore N., Kpodo J., Kropp I., Eeswaran R., Belton B., and Haque M. M. 2021. "Harnessing Machine Learning Techniques for Mapping Aquaculture Waterbodies in Bangladesh." Remote Sensing 13(23), 4890. https://doi.org/10.3390/rs13234890.D67.
69	2021	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Fonsah, E. "Revolutionizing Agriculture in Africa." University of Ibadan Seminar, Ibadan, Nigeria, August 2021.
70	2021	Kenya	Publication	Samaki Salama	Iannotti, L., Blackmore, I., Cohn, R., Chen, F., Gyimah, E. A., Chapnick, M., and Humphries, A. 2021. "Aquatic animal foods for nutrition security and child health." Food and Nutrition Bulletin, 43(2), 127–47. https://doi.org/10.1177/03795721211061924.
71	2021	Nigeria	Presentation	Farming Insects in Nigeria	Pechal, J.L. "Applications of Insect-Microbiome Interactions." Invited Seminar (Virtual), Texas A&M University, February 2021.
72	2021	Zambia	Presentation	Fish4Zambia (QS)	Ragsdale, K., Read-Wahidi, M. R., Marinda, P., Pincus, L., Torell, E. & Kolbila, R. 2021. "Using the Household Hunger Scale to explore food insecurity among smallscale fishers, processors, and traders at Zambia's Lake Bangweulu: Fish4Zambia Results." Poster Presentation, 2021 Women and Gender in International Development Conference, Blacksburg, Virginia, February 2021. [Converted to virtual meeting due to Covid-19 pandemic.]
73	2021	Zambia	Presentation	Fish4Zambia (QS)	Ragsdale, K., Read-Wahidi, M. R., Marinda, P., Pincus, L., Torell, E., and Kolbila, R. 2021. "Fish4Zambia: Focusing a gender lens on household-level hunger among Lake Bangweulu fisher families." Invited Presentation, SSRC Brown Bag Speaker Series, Social Science Research Center, Mississippi State University, Virtual.
74	2021	Zambia	Publication	Zambia Crayfish	Rice, M. A. 2021. "Intensive Fishing Effort and Market Controls as Management Tools for Invasive Aquatic Species: A Review." Asian Fisheries Science 34(4), 383-392. https://www.asianfisheriessociety.org/publication/downloadfile.php?id=1384&file=Y0dSbUx6QXdNVE01T0Rrd01ERTJOREV3TlRBMk5qSXVjR1Jt.
75	2021	Zambia	Publication	Replacing fishmeal with single cell proteins (QS)	Rodrigue Yossa, Alexander M. Greiling, Rose Komugisha Basiita, Masautso E. Sakala, Wes Baumgartner, Adam Taylor, and Delbert M. Gatlin. 2021. "Replacing fishmeal with a single cell protein feedstuff in Nile tilapia Oreochromis niloticus diets, Dry yeast product DY-Pro in Nile tilapia diets." Animal Feed Science and Technology 281, (November 2021). 115089. https://doi.org/10.1016/j.anifeedsci.2021.115089.

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76	2021	N/A	Publication	N/A	Torell, E., Manyungwa-Pasani, C., Bilecki, D., Gumulira, I., and Yiwombe, G. 2021. "Assessing and advancing gender equity in Lake Malawi's small-scale fisheries sector." Sustainability 13(23). https://doi.org/10.3390/su132313001.
77	2020	Bangladesh	Publication	N/A	Aftab Uddin, S., Hussain, M. G., Abdullah Al, M., Failler, P., and Drakeford, B. M. 2020. "On the potential and constraints of mariculture development in Bangladesh." Aquaculture International. https://doi.org/10.1007/s10499-020-00643-9.
78	2020	Nigeria	Presentation	Aquaculture Diversification in Rural Communities	Ajani, E. K., and Omitoyin, B. O. 2020. "The project objectives and implementation arrangement." Presentation, Stakeholder Workshop and Innovation Platform in Kebbi and Ebonyi state, Birnin-Kebbi, and Abakaliki, Nigeria, September 2020.
79	2020	Bangladesh	Presentation	Genome sequencing (QS)	Alam, M., and Khan, M. 2020. "Economics of Rohu (*Labeo rohita*) based carp polyculture in Bangladesh and necessity for genetic improvement programs." Presentation, Mississippi State University, MS, March 2020.
80	2020	Kenya	Presentation	Coral Reef Fishery Sustainability	Humphries, A. 2020. "Working towards ecosystem health solutions in Kenya." Presentation, University of California, Santa Cruz Coastal Science and Policy Seminar Series, Santa Cruz, CA, February 24, 2020.
81	2020	Bangladesh	Presentation	N/A	Hussain, M. G. 2020. "Blue Economy development in Bangladesh under the context of SDG 14." Keynote Presentation, 7th Session on Blue Economy Development in Bangladesh under the Context of SDG 14, “Life Below Water,” Dhaka, Bangladesh, July 2020.
82	2020	Zambia	Presentation	Fish4Zambia (QS)	Marinda, P., Noelle, N., Genschick, S., and Thilsted, S.H. 2020. "The potential contribution of small fish to dietary nutrient adequacy and nutritional status of women of reproductive age and under-five children in Zambia." Poster Presentation, Nutrition-Sensitive Fish Agri-Food Systems Workshop, Lusaka, Zambia, February 24-25, 2020.
83	2020	Zambia	Presentation	Fish4Zambia (QS)	Marinda, P., Ragsdale, K., Read-Wahidi, M.R., Kolbila, R., Pincus, L., and Torell, E. 2020. "Fish4Zambia: Research to close fish consumption and nutrition gaps in Zambia’s Lake Bangweulu region." Oral Presentation, Nutrition-Sensitive Fish Agri-Food Systems Workshop, Lusaka, Zambia, February 24, 2020.
84	2020	Bangladesh	Publication	N/A	Patil, P. G., Virdin, J., Colgan, C. S., Hussain, M. G., Failler, P., and Veigh, T. 2020. "Initial measures of the economic activity linked to Bangladesh's ocean space, and implications for the country's blue economy policy objectives." Journal of Indian Ocean Rim Studies 3(1), 1-13. https://www.researchgate.net/publication/342170897_Initial_measures_of_the_economic_activity_linked_to_Bangladesh's_ocean_space_and_implications_for_the_country's_blue_economy_policy_objectives#fullTextFileContent.

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85	2020	Zambia	Presentation	Fish4Zambia (QS)	Ragsdale, K., Kolbila, R., Marinda, P., Read-Wahidi, M.R., Pincus, L., and Torell, E. 2020. "Fish4Zambia preliminary results: Exploring food insecurity among men and women in Zambia's Lake Bangweulu region." Accepted Oral Presentation, Society for Applied Anthropology Annual Meeting, Albuquerque, NM, March 17-2, 2020. [conference canceled due to COVID-19]
86	2020	Zambia	Presentation	Fish4Zambia (QS)	Ragsdale, K., Marinda, P., Read-Wahidi, M., Pincus, L., Torell, E., and Kolbila, R. 2020. "Fish4Zambia: Exploring food insecurity among fishing value chain actors at Lake Bangweulu." Accepted poster presentation, Fourth International Conference on Global Food Security, Montpellier, France. [conference canceled due to COVID-19]
87	2020	N/A	Publication	N/A	Torell, E. C., Jamu, D. M., Kanyere, G. Z., Chiwaula, L., Nagoli, J., Kambewa, P., Brooks, A., and Freeman, P. 2020. "Assessing the economic impacts of post-harvest fisheries losses in Malawi." World Development Perspectives 19. https://doi.org/10.1016/j.wdp.2020.100224.
88	2020	Kenya	Presentation	SecureFish (QS)	Wamukota, A. 2020. "Securefish Kenya." Presentation, Wildlife Conservation Society - Annual Fishers Forum, Tiwi Beach, Kenya, January 2020.
89	2020	Kenya	Presentation	SecureFish (QS)	Wamukota, A. 2020. "SecureFish Kenya." Presentation, Unlocking a Resilient Blue Economy, Workshop organized by CordIo EA/IUCN, Mombasa, Kenya. March 12, 2020.
90	2020	Kenya	Presentation	SecureFish (QS)	Wamukota, A. 2020. "SecureFish Kenya." Presentation, Annual Fishers Forum, Diani, Kenya, January 9, 2020.
91	2020	Zambia	Publication	Replacing fishmeal with single cell proteins (QS)	Yossa, R., Gatlin, D., Greiling, A.M., Komugisha Basiita, R., Sakala, M.E., Baumgartner, W., Corace, D., and Taylor, A. 2020. "Field Notes - Replacement of fisheries-derived fishmeal with yeast-derived proteins for sustainable aquaculture in Zambia." The Chicago Council on Global Affairs Global Food for Thought.
92	2019	N/A	Presentation	N/A	Allred, S., Ciaramella, M., Schilling, M. W., Petrie-Hanson, L., & Allen, P. J. (2019, March). Catfish responses to pond and harvest stressors and consequences for muscle quality. Paper presented at the meeting of the World Aquaculture Society, New Orleans, LA.
93	2019	N/A	Publication	N/A	Allred, S., Shao, W., Schilling, M. W., Petrie-Hanson, L., & Allen, P. J. (2019). An assessment of red fillet prevalence in the catfish industry. Aquaculture, 507, 203-210. https://doi.org/10.1016/j.aquaculture.2019.04.020.
94	2019	N/A	Publication	N/A	Carvalho, P. G., Jupiter, S. D., Januchowski-Hartley, F. A., Goetze, J., Claudet, J., Weeks, R., Humphries, A., & White, C. (2019). Optimized fishing through periodically harvested closures. Journal of Applied Ecology, 56, 1927-1936. https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/1365-2664.13417.

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95	2019	N/A	Publication	N/A	Chesser, B. M., Green, C. C., & Allen, P. J. (2019). Egg production of Gulf Killifish is dependent on broodstock rearing density but not spawning substrate surface area. North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10087.
96	2019	N/A	Presentation	N/A	Chesser, B., & Allen, P. J. (2019). Effect of broodstock density and spawning substrate surface area on reproductive output of Gulf Killifish in commercial-scale recirculating aquaculture systems. Paper presented at the meeting of the World Aquaculture Society, New Orleans, LA.
97	2019	Bangladesh	Presentation	Genome sequencing (QS)	Dey, M. M. (2019, December 27). Value chains in aquaculture and fisheries in Bangladesh: Recent advances and future research directions [Invited keynote presentation]. Fisheries Society of Bangladesh Biannual Conference, Mymensingh, Bangladesh.
98	2019	Bangladesh	Presentation	Genome sequencing (QS)	Dey, M., Alam, M., Khan, M., & Hossain, M. (December 2019). Economics of Rohu based carp polyculture in Bangladesh: Efficiency, yield gap and nutritional perspectives. Presentation at The Biennial Conference of Fisheries Society of Bangladesh 2019, Mymensingh, Bangladesh.
99	2019	Bangladesh	Publication	N/A	Failler, P., & Hussain, M. G. (2019). Policy interventions for the development of the Blue Economy in Bangladesh. Journal of Ocean and Coastal Economics, 6(2). https://doi.org/10.15351/2373-8456.1099.
100	2019	Bangladesh	Publication	N/A	Failler, P., & Hussain, M. G. (2019, May 9). A brief on EU-BGD joint collaboration on Blue Economy in Bangladesh [blog post]. https://buff.ly/2VKXQoJ.
101	2019		Presentation	N/A	Guy, E. L., Menghe H., Mischke, C. C., Colvin, M., & Allen, P. J. (2019). Spawning and rearing suckers: lessons from Black Buffalo. Paper presented at the meeting of the World Aquaculture Society, New Orleans, LA.
102	2019		Publication	N/A	Guy, E. L., Mischke, C. C., Colvin, M. E., Allen, P. J. (2019). Zooplankton selectivity by Black Buffalo in fertilized ponds. North American Journal of Aquaculture. https://doi.org/10.1002/naaq.10089.
103	2019	Bangladesh	Presentation	Genome sequencing (QS)	Hossain, M. E. (2019, December 31). Economics of rohu based carp polyculture in Bangladesh: Efficiency, yield gap and nutritional perspectives. Bangladesh Agricultural University, Mymensingh.
104	2019		Publication	N/A	Humphries, A. T., Gorospe, K. D., Carvalho, P.G., Yulianto, I., Kartawaijaya, T., Campbell, S. (2019). Catch composition and selectivity of fishing gears in a multi-species Indonesian coral reef fishery. Frontiers in Marine Science, 6(378). https://doi.org/10.3389/fmars.2019.00378.

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105	2019	Bangladesh	Publication	N/A	Hussain, G., Kohinoor, A., Rahman, M., Rahman, Z, & Nguyeh, N. H. (2019, April 12). Bangladesh's tilapia aquaculture industry shows resilience: Recent successes traced to genetically improved farmed tilapia, effective fry dissemination [blog post]. https://tilapialoversociety.com/2019/04/12/bangladeshs-tilapia-aquaculture-industry-shows-resilience-gulam-hussain-ph-d-ahm-kohinoor-ph-d-mr-moshiur-rahman-zillur-rahman-and-nguyen-hong-nguyen-ph-d/.
106	2019	Bangladesh	Presentation	N/A	Hussain, M. G. (2019, December 26). Aquaculture and fisheries sector in Bangladesh: Overview and government priorities [Paper presentation]. Challenges, Needs and Potentials of Aquaculture and Fisheries in Bangladesh seminar, Mymensingh, Bangladesh.
107	2019	Bangladesh	Presentation	N/A	Hussain, M. G. (2019, December 27). Potentials of marine fisheries and mariculture under the concept of blue economy development in Bangladesh [Keynote presentation]. Fisheries Society of Bangladesh Biennial Conference, Mymensingh, Bangladesh.
108	2019	Bangladesh	Presentation	N/A	Hussain, M. G. (2019, December). Aquaculture and fisheries sector in Bangladesh: Overview and government priorities. Presentation at Challenges, Needs and Potentials of Aquaculture and Fisheries in Bangladesh organised by "Genome Sequencing and Development of SNP Markers from Rohu" FIL QuickStart Project in Bangladesh, Mymensingh, Bangladesh.
109	2019	Bangladesh	Presentation	N/A	Hussain, M. G. (2019, November 2). Sustainable aquaculture and fisheries development in Bangladesh: Country needs and sectoral priorities [Keynote presentation]. Bangladesh Fisheries Research Forum Sustainable Aquaculture and Fisheries Development in Bangladesh: Country Needs and Sectoral Priorities seminar, Dhaka, Bangladesh.
110	2019	Bangladesh	Publication	N/A	Hussain, M. G. (2019, October 29). Improved breeding and farming practices of tilapia in Bangladesh [blog post]. https://tilapialoversociety.com/2019/10/29/improved-breeding-and-farming-practices-of-tilapia-in-bangladesh-m-gulam-hussain/?fbclid=IwAR1qCywLx0Vj6rSEez_Fq4pVqB_SobQ7zYSqw5033cKo_RZvo916d1oXjUw.
111	2019	Bangladesh	Publication	N/A	Hussain, M. G., Failler, P., & Sarker, S. (2019). Future importance of maritime activities in Bangladesh. Journal of Ocean and Coastal Economics, (6)2, Article 3. https://doi.org/10.15351/2373-8456.1104.
112	2019	Bangladesh	Publication	N/A	Hussain, M. G., Uddin, S. A., & Failler, P. (2019). Potentials for the development of blue economy: Prospects and challenges of mariculture in Bangladesh. Journal of Bangladesh, 9(1), 7-21.

No.	Year	Country	Type	Activity name	Citation
113	2019		Presentation	N/A	Iannotti, L. (2019, June). Effective pathways towards reducing chronic malnutrition. In Ensuring children's cognitive and physical development through animal source foods. Symposium conducted by Feed the Future Innovation Lab for Livestock Systems, Washington DC.
114	2019		Presentation	N/A	Iannotti, L. (2019, June). Lulun II: Follow-up cohort study. In Young child nutrition, eggs, and poultry production. Symposium conducted at the annual conference of the American Society for Nutrition.
115	2019		Presentation	N/A	Iannotti, L. (2019, May). Of Shores & Savannas: Evolutionary aspects of animal source food nutrition. Presentation at the Aligning the Food System for Improved Nutrition in Animal Source Foods conference, Davis, CA.
116	2019	Bangladesh	Presentation	Genome sequencing (QS)	Khan, M. A. (2019, December 26). Economics of rohu based carp polyculture in Bangladesh: Efficiency, yield gap and nutritional perspectives [Paper presentation]. Challenges, Needs and Potential of Aquaculture and Fisheries in Bangladesh workshop, Mymensingh, Bangladesh.
117	2019	Zambia	Presentation	Fish4Zambia (QS)	Kolbila, R., Ragsdale, K., Marinda, P., Read-Wahidi, M., Pincus, L, & Torell, E. (2019, October). Fish4Zambia: Research to close fish consumption and nutrition gaps in Zambia. Presentation at the 2019 Mississippi State University Graduate Research Symposium, Mississippi State, MS.
118	2019	N/A	Presentation	N/A	Lawrence, M. (2019, March). Use of essential oils as alternative treatment to control *Edwardsiella ictaluri* infection in catfish. Presentation at the World Aquaculture Society annual meeting, New Orleans, LA.
119	2019	N/A	Presentation	N/A	Lawrence, M. (2019, May). Feed the Future Innovation Lab for Fish: Advancing the fish value chain and human nutrition. Presentation at the WorldFish-USAID Knowledge Sharing Session, Washington, DC.
120	2019	N/A	Presentation	N/A	Lawrence, M. (2019, October 7). Microbial genomics as a tool for vaccine development [seminar]. University of Alabama at Birmingham Department of Biology, Birmingham, AL.
121	2019	N/A	Presentation	N/A	Lawrence, M. (2019, September). Improved nutrition security through increased access to and consumption of fish. In Accessing innovation lab food security & resilience innovations. Presentation at the annual meeting of the Feed the Future Innovation Labs, Washington, DC.
122	2019	N/A	Presentation	N/A	Lawrence, M., Elhassan, O., Arthur, R., Hanson, L., Gaunt, P., Bin, H., & Sharan, V. (2019, July). Lightning talks. In T. Pesek (Moderator), Aquaculture biosecurity: The invisible threat of antimicrobial resistance. Congressional briefing hosted by the Food and Agriculture Organization of the United Nations and the Mississippi State University Global Center for Aquatic Food Security, Washington, DC.

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123	2019	N/A	Publication	N/A	Omer, A.R., Henderson, J., Falconer, L., Kroger, R., & Allen, P. J. (2019). Economic costs of using tailwater recovery systems for maintaining water quality and irrigation. Journal of Environmental Management. https://doi.org/10.1016/j.jenvman.2019.01.038.
124	2019	Bangladesh	Publication	N/A	Patil, P. G., Virdin, J., Colgan, C. S., Hussain, M. G., Failler, P., & Veigh, T. (2019). Initial measures of the economic activity linked to Bangladesh's ocean space, and implications for the country's Blue Economy policy objectives. Journal of Ocean and Coastal Economics, 6(2). https://doi.org/10.15351/2373-8456.1119.
125	2019	N/A	Publication	N/A	Stewart, C., Caswell, B., Iannotti, L., Lutter, C., Arnold, C., Chipatala, R., Prado, E., & Maleta, K. (2019). The effect of eggs on early child growth in rural Malawi: The Mazira Project randomized controlled trial. American Journal of Clinical Nutrition.
126	2019	N/A	Publication	N/A	Stewart, H. A., Aboagye, D. L., Ramee, S. W., & Allen, P. J. (2019). Effects of acute thermal stress on acid-base regulation, haematology, ion-osmoregulation and aerobic metabolism in channel catfish (*Ictalurus punctatus*). Aquaculture Research. doi: https://doi.org/10.111/are.14093.
127	2019	N/A	Publication	N/A	Surathkal, P., & Dey, M. M. (2019). Import penetration and price relationships: An empirical analysis of the U.S. catfish market. Aquaculture Economics & Management. https://doi.org/10.1080/13657305.2019.1699199.
128	2019	Ghana	Publication	N/A	Torell, E., Bilecki, D., Owusu, A., Crawford, B., Beran, K., & Kent, K. (2019). Assessing the impacts of gender integration in Ghana's fisheries sector. Coastal Management. https://doi.org/10.1080/08920753.2019.1669098.