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

Feed the Future Innovation Lab for Fish

Annual Report October 1, 2021 – September 30, 2022

Cooperative Agreement 7200AA18CA0030

USAID
FROM THE AMERICAN PEOPLE

MISSISSIPPI STATE UNIVERSITY
GLOBAL CENTER FOR AQUATIC HEALTH AND FOOD SECURITY

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Cooperative Agreement 7200AA18CA0030

November 30, 2022

Prepared for:

Agreement Officer's Representative (AOR)

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

Bureau for Resilience and Food Security (RFS)

United States Agency for International Development (USAID)

Prepared by:

Mississippi State University

Global Center for Aquatic Health and Food Security

Mississippi State, Mississippi 39762

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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 College of Veterinary Medicine.

Members of the Management Entity

- Mark L. Lawrence, Director (88%)
- Stephen Reichley, Risk Mitigation Specialist, began as Deputy Director in September (25%)
- Peter Allen, Productivity Frontier Specialist (8%)
- Jared Dees, Grants and Contracts Manager (90%)
- Alaina Dismukes, Communications Specialist (90%)
- Shauncey Hill, Program/Finance Manager (100%)
- Kathleen Ragsdale, Gender and Youth Equity Specialist (20%)
- Mary Read-Wahidi, Gender and Youth Equity Co-Specialist (15%)
- Laura Zseleczky, Communications Manager (100%)

External Advisory Board

The Fish Innovation Lab Management Entity (ME) is advised by the Fish Innovation Lab External Advisory Board (EAB), who 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

- Bryan McCoy, Special Projects Director of FirstWave Group
- Michael Phillips, Director and Co-founder of FUTUREFISH
- Melba B. Reantaso, Team Leader (NFIMF: Food Safety, Nutrition and Health), Fisheries and Aquaculture Division (NFI), Food and Agriculture Organization of the United Nations (FAO)
- Rohana Subasinghe, Technical Lead, WorldFish Nigeria
- Karen Veverica, Former Director, Auburn University E.W. Shell Fisheries Research Center

Countries Where the Fish Innovation Lab Works

In federal fiscal year (FY) 2022, the Fish Innovation Lab implemented 19 research for development activities in Bangladesh, Nigeria, Kenya, Zambia, Cambodia, Malawi, and Ghana, as well as a buy-in activity covering Peru, Madagascar, the Philippines, and the Pacific Islands (Figure 1).

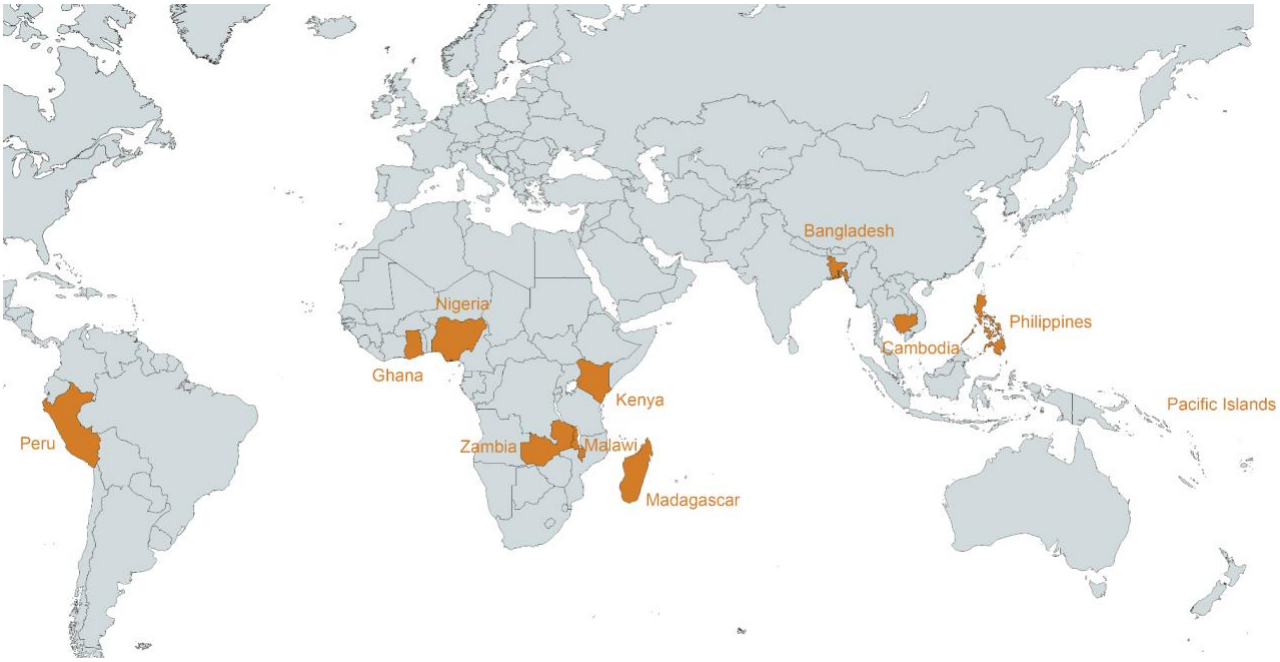

Figure 1: Location of Fish Innovation Lab Activities

Fish Innovation Lab Management Entity Partners

Research Triangle Institute (RTI) International

- Rebecca Jeudin, Monitoring, Evaluation, and Learning Advisor (70%)
- Joanna Springer, Resilience Specialist (7%)

Texas State University (TSU)

- Madan Dey, Asia Specialist (25%)

University of Rhode Island (URI)

- Elin Torell, Deputy Director until September and Human Outcomes Specialist (38%)
- Austin Humphries, East Africa Specialist (25%)
- Karen Kent, West Africa Specialist (17%)
- Glenn Ricci, Capacity Development Specialist (33%)
- Laura Skrobe, Fisheries and Program Management (33%)

Washington University in St. Louis (WUSTL)

- Lora Iannotti, Nutrition Specialist (8%)

Regional Coordinators

- Md. Gulam Hussain, Asia Coordinator (50%)
- Sunil Siriwardena, West Africa Coordinator (50%)
- Andrew Wamukota, East Africa Coordinator (50%)

Abbreviations and Acronyms

AAM	Aquaculture Africa Magazine
AMR	Antimicrobial Resistance
AOR	Agreement Officer's Representative
APHA	American Public Health Association
BC	Bighead Catfish
BMP	Best Management Practice
BMU	Beach Management Unit
BSF	Black Soldier Fly
BSFL	Black soldier fly larvae
DoF	Department of Fisheries
DNA	Deoxyribonucleic acid
DWF	Distant Water Fleets
EAB	External Advisory Board
EH&S	Environmental Health and Safety
EMMP	Environmental Management and Mitigation Plan
ENGOs	Environmental Non-governmental Organizations
ESBL	Extended Spectrum Beta Lactamase
FAO	Food and Agriculture Organization of the United Nations
FY	Fiscal Year
G3	Generation 3
GIFT	Genetically Improved Farmed Tilapia
GIS	Geographic Information System
GRADA-FIL	Gender Responsive Aquaculture/Fisheries Development Assessment
HC	Host Country
HICD	Human and Institutional Capacity Development
HIES	Household Income Expenditures Survey
IACUC	Institutional Animal Care and Use Committee
IAFP	International Association for Food Protection
IEE	Initial Environmental Examination
IITA	The International Institute of Tropical Agriculture
IMC	Indian Major Carp
IRB	Institutional Review Board
IYC	Infants & Young Children
LSME	Lean Subject Matter Expert
ME	Management Entity
MEL	Monitoring, Evaluation, and Learning

MSU	Mississippi State University
NFIMF	Food Safety, Nutrition and Health
NFI	Fisheries and Aquaculture Division
NGO	Nongovernmental Organization
PCR	Polymerase Chain Reaction
PHFLA	Post-Harvest Fish Loss Assessment
PI	Principal Investigator
RFS	Bureau for Resilience and Food Security
RTI	Research Triangle Institute
RUA	Royal University of Agriculture
SAIN	Sustainable Agricultural Intensification and Nutrition
TSU	Texas State University
UI	University of Ibadan
UNZA	The University of Zambia
UoC	The 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).

Gender Integration: Strategies employed to ensure women’s and men’s attitudes, roles, responsibilities, concerns, and experiences are an integral dimension of the design, implementation, monitoring, and evaluation of research and extension. Differences are recognized and routinely addressed for all activities.

Gender Equality: Norms, values, attitudes, and perceptions required to attain equal status between women and men without neutralizing the biological differences between women and men.

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) began in September 2018 and has completed four years. In FY 22, the Fish Innovation Lab implemented 19 competitively awarded and commissioned research activities and one buy-in that addressed the Fish Innovation Lab theory of change. The geographic coverage of the Fish Innovation Lab includes eleven countries: Bangladesh, Cambodia, Ghana, Kenya, Madagascar, Malawi, Nigeria, the Pacific Islands, Peru, the Philippines, and Zambia.

Fish Innovation Lab accomplishments in advancing productivity (Area of Inquiry 1) include improving efficiency of aquaculture production, feed production, and fish processing in Nigeria; implementing integrated rice-fish farming experimental plots in Nigeria; and supporting improved genetics of carp species in Bangladesh through family selection and sperm cryopreservation where results indicate that fish harvested from farm trials of genetically improved rohu carp weighed 37% more than unimproved carp, and seeds from cryopreserved sperm grew bigger than seeds from sperm of hatchery-origin males. Fisheries productivity was also advanced by a fully functional searchable photo identification catalog of freshwater fishes harvested in Cambodia and community-led fish landing monitoring activities in Kenya.

The Fish Innovation Lab addressed reducing and mitigating risks (Area of Inquiry 2) by launching an on-line E-AquaHealth diagnostic extension service platform at the University of Ibadan in Nigeria; identifying major foodborne pathogens on fish and behaviors associated with food safety by fish processors in Dhaka City in Bangladesh; and characterizing pathogenic bacteria responsible for tilapia mortalities in Zambia for autogenous vaccine development.

Human outcomes (Area of Inquiry 3) were addressed by training on remote sensing technologies for fish pond identification and producing extension videos in Bangladesh; developing low literacy tools used by women fish processors resulting in increased knowledge and customer engagement on nutrition and food safety in Nigeria; conducting nutrition training and sensory panels on complimentary foods integrating fish powder in Zambia; increasing mothers/caregivers use of fish in diets and increasing fisher's income from modified fishing gear in Kenya; conducting crayfish trapping studies in Zambia to understand the distribution of the invasive species in Lake Kariba and the Kafue floodplain; surveying 820 fish farmers in Bangladesh on the status of the aquaculture value chain; and analyzing 915 oyster samples for 16 minerals in Ghana to inform decision making on livelihoods and nutrition for women shellfishers.

The Fish Innovation Lab Management Entity (ME) and sub awardees worked to achieve impacts within four cross-cutting themes: capacity development, gender equity and youth engagement, nutrition, and resilience. Capacity development activities engaged U.S.-based and in-country teams, enabling the formation of an aquaculture and fisheries community of practice; long-term, hands-on, graduate training of students in country; and engagement of stakeholders, community members, and end users through short-term trainings and direct involvement in research activities. The management entity also launched the Fish Innovation Lab student network. In Bangladesh, collaboration between the research teams and government entities raised the interest of government officials to explore avenues for implementation. Gender and youth equity specialists led or participated in 25 gender/youth-related activities. Several projects included specific gender equality goals into their efforts. Research teams engaged youth in rice-fish farming capacity enhancement activities in Nigeria, which had 82% youth participation. In addition, fish weight-length training in Kenya had 56% youth participation and 39% female participation. Nutrition approaches and results were presented at the 2021 Norman E. Borlaug International Dialogue. The resilience specialist launched online training in resilience for PIs and worked with seven projects to develop more robust frameworks for resilience in their approaches.

The Fish Innovation Lab ME implemented several activities aiming to encourage cross-activity learning. This included quarterly virtual learning sessions, the Fish Innovation Lab Annual Meeting, and the in-person Bangladesh Aquaculture Sector meeting.

Focus Country Key Accomplishments

The Fish Innovation Lab implements activities in West Africa (Nigeria and Ghana), Eastern and Southern Africa (Kenya, Zambia, and Malawi), and Asia (Cambodia and Bangladesh). A list of the activities funded through the Fish Innovation Lab is shown in Appendix 1.

1. **Nigeria:** The Fish Innovation Lab has five activities in Nigeria. They are working to implement integrated rice-fish aquaculture; evaluate integrated insect-to-fish farming systems; employ Lean production systems to improve efficiency in the aquaculture sector; develop strategies to reduce fish disease impacts on catfish and tilapia aquaculture; and build capacity among women and youth fish processors to produce high quality, safe, and nutritious processed fish products. These activities contribute to the Lab's objectives to advance aquaculture productivity, mitigate risks, and improve human outcomes. In FY22, teams developed four rice-fish technological packages and identified best performing preferred species for rice-fish production and four low-cost good-quality locally available fish feed options; identified 400 bacterial strains from catfish and tilapia farms; identified fish and insect farmers for field trials; engaged 219 farms to improve farm efficiency by applying Lean management tools to identify and address incidents of lost efficiency; and conducted three market surveys on fish prices.

    - **local capacity strengthening** – A catfish and tilapia disease workshop 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.
    - **gender equality** – Introduction of low literacy tools targeting women and youth fish processors effectively supported customer engagement by informing about them about the benefits of fish consumption and helped to improve marketing efforts. The tools increased women fish processors knowledge about nutrition and health and empowered them to improve business decision-making.
    - **youth engagement** – Rice-fish farming capacity enhancement activities had 82% youth participation.
    - **digital** – The E-Aqua Health diagnostic extension platform was launched by the University of Ibadan (UI) for farm cluster leaders, resident veterinarians, and UI researchers. It enhances prompt response to disease outbreaks and supports fish farmers.
    - **climate change and climate finance** – Activities to reduce fish disease impacts contribute to resilience at the community, system, national, and regional level using a cluster management approach to reduce disease exposure; addressing antimicrobial resistance by encouraging reduced antibiotic use; and contributing to an improved regulatory environment.
    - In FY23, teams will complete surveys and analyses, training, field trials, and prepare publications.

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    In-Country Partner Organizations: University of Ibadan, WorldFish, University of Calabar, International Institute of Tropical Agriculture (IITA).

2. **Ghana:** The Fish Innovation Lab has one activity in Ghana, which aims to investigate the contribution of oyster consumption to iron and zinc intakes of women shellfishers in three estuary sites. This case study will also provide information to assess whether heavy metal

contamination of oysters is a health concern. This research aligns with the lab's goals to improve human outcomes among participants of the fisheries sector. In FY22, the team completed statistical analysis of the women's nutrient intakes using 24-hour recalls, including intake of oysters, specific dietary nutrients, and contribution of oysters to total iron and zinc intakes; analyzed 915 oyster samples from three sites for 16 minerals, including macro minerals (e.g., calcium, magnesium, phosphorus, potassium, and sodium), trace minerals (e.g., chromium, cobalt, copper, iron, manganese, nickel, selenium, and zinc), and heavy metals (e.g., cadmium, mercury, and lead); initiated analysis of arsenic; and completed analysis of the health risks of oyster consumption among the women shellfishers for cadmium, mercury, and lead.

- **local capacity strengthening** – Assessment results provide authorities and decision-makers with the information necessary to spur action that will enhance the sustainability of oyster production and avert potential issues of heavy metal contamination in Ghanian estuaries.
- **gender equality** – There is a research gap on the nutrition of women shellfishers in Ghana. This research activity is studying a sample of 504 women shellfishers at three estuary sites in Ghana. Findings and recommendations will build a stronger evidence base to help influence the health and nutrition of women shellfishers at the three sites and similar settings in Ghana and in West Africa.
- In FY23, the team will continue to evaluate health risks of oyster consumption; complete oyster sample analysis for arsenic, including Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI); and prepare a manuscript, providing findings and recommendations on the role of oysters as a source for iron and zinc among women shellfishers in West Africa, using Ghana as a case study.

  In-Country Contact Information: Seth Adu-Afarwuah, boaddo@ug.edu.gh, University of Ghana.

  In-Country Partner Organizations: University of Ghana.

3. **Kenya:** The Fish Innovation Lab has two activities in Kenya working to secure small-scale fisheries for healthy nutrition and ecosystems and to improve fisheries management and sustainability in coral reefs. These activities promote healthy nutrition, income growth, and sustainable fisheries through community capacity building in alignment with the lab's objective to build stakeholder resilience. In FY22, teams conducted preliminary analysis of catch data comparing catch obtained through locally fabricated traps modified with an escape gap and unmodified traps. Results showed that modified traps catch more fish biomass and fewer juveniles, while increasing fisherman income derived from catches. Teams continued a nutrition social marketing campaign communicating key messages across platforms (e.g., home visits, workshops, calendars, and cooking classes, targeting family members and community health workers) to improve nutritional outcomes through behavior change; completed 31 transect surveys to assess fish biomass; completed films of underwater surveys and participant interviews; and developed a fish biomass training manual used by community data collectors for recording landed fish.

   - **local capacity strengthening** – Mothers/caregivers reported improved practices in child feeding and care, while supporting efforts to train other women. Fishermen reported increased revenue from catches in modified traps.
   - **gender equality** – Community member trainings on fish biomass included 39% female and 56% youth. Collaboration with government and non-profit organizations supported women empowerment by supporting them in efforts to champion women's rights.
   - **digital** – A mobile app enabled community data collectors and county fisheries officers to monitor fish landings by recording fish landed by family and fishing effort to increase awareness, inform stakeholders on reef status and community capacity, and make recommendations to relevant bodies.

- **climate change and climate finance** – By using mobile phones in data collection, teams identified heavy rains as one of the climatic shocks that increased network outages and affected timely phone charging. Increased fishermen revenue from catches in modified traps is contributing to create new, and expand current, fish businesses, buffering them during low fishing seasons and improving adaptive capacity. Some fishermen reported making more modified traps, adopting the sustainable fishing practices learned.
- In FY23, teams will conduct qualitative data collection, a fish value chain market survey, and fish landing monitoring.
  In-Country Contact Information: Andrew Wamukota, a.wamukota@pu.ac.ke, Pwani University; Elizabeth Kamau-Mbuthia, ekambu@yahoo.com, Egerton University; Emmanuel Mbaru, mbaru08@gmail.com, Kenya Marine and Fisheries Research Institute.

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

4. **Zambia:** The Fish Innovation Lab has three activities in Zambia, which are working to optimize the delivery mode of a multivalent bacterial fish vaccine; increase the quality/quantity of fish to improve nutrition and food security, especially for women of reproductive age; and investigate the biology, ecology, and population of invasive crayfish in Lake Kariba and Kafue River. In alignment with the lab's goals, the objective of these activities is to mitigate risk and improve human outcomes, particularly of women and youth. In FY22, teams obtained crayfish traps similar to the Australian-style traps for fishing trials in Zambia to support research on the catchability of crayfish and determine cost effectiveness; shared a protocol to conduct a length-frequency analysis to assess the status of fishery stocks with government officials; developed and tested the Complementary Food for Africa (ComFA) + Dried Fish Powder for enhanced nutrition benefiting mothers and infants in vulnerable households; and isolated and identified key bacteria associated with diseased fish.

   - **local capacity strengthening** – Activities to identify diseased fish and collect samples on farms improved farmers' capacity to understand the dynamics of fish disease.
   - **gender equality** – Teams held a training on nutrition for healthy women and children in the first 1,000 days of life with 79% women participants. This training encouraged fish consumption in the first 1,000 days of life by providing mothers with knowledge of how to improve child nutrition, health, and household diet.
   - **youth engagement** – Women and youth participation in the aquaculture industry is significantly increasing. Activities to identify fish disease targeted young farmers, including women.
   - **digital** – A paper survey of cray fisheries practices and basic post-harvest utilization was developed. After piloting the survey and analyzing the context, it was turned into an online survey using Qualtrics.
   - In FY23, teams will assess whether bacteria isolated from diseased fish are the cause of disease; develop vaccine formulation; conduct crayfish trapping studies and harvest and utilization surveys; and develop a database to determine country-wide presence or absence of crayfish. Teams will work to identify potential community-based organizations as partners to train women and youth entrepreneurs on the production of the ComFA+Fish product as a microenterprise.

     In-Country Contact Information: Netsayi Mudege, n.mudege@cgiar.org, WorldFish; Pamela Marinda, pamela.marinda@unza.zm, University of Zambia.

     In-Country Partner Organizations: WorldFish, University of Zambia.

5. **Malawi:** The Fish Innovation Lab commissioned an activity to focus on fish feed production integrating efforts to promote small scale BSF production (targeting small- and medium-

scale fish farmers) and advance larger scale production in Africa. The activity was to contribute to the lab's objectives to advance aquaculture productivity, but it did not start in a timely manner and has been closed.

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In-Country Partner Organizations: Lilongwe University of Agriculture and Natural Resources, LM Aquaculture Limited.

6. **Cambodia:** The Fish Innovation Lab has two research activities in Cambodia, working to develop and disseminate technologies on formulated sustainable feeds for bighead catfish (BC); improve sustainable fisheries management through community-based monitoring of fish populations; and dissemination of knowledge about fish processing techniques. These activities align with the lab's goals by promoting methods to improve income, promote gender equality, empower youth, provide nutritious food, and strengthen resilience. In FY22, teams collected fisheries harvest data, with 15 local fishers recording >32,433 entries for >52,300 fish in the Sre Ambel River. Data is accessible on the iFISH data analysis and visualization platform, helping local fisheries communities and other stakeholders evaluate current harvest and assess stock recovery. Teams improved knowledge about fish related taste preferences in communities through a Sensory Evaluation of Fish Product and improved knowledge among participating fishers about preservation techniques (e.g., smoking tunnel for fish). This innovation has the potential to add value to the fishers' work, while improving community food security. For the formulation of sustainable feeds for BC, installation of a wet lab is almost complete, and the team trained local farmers and staff from the Royal University of Agriculture on the application of scientific aquaculture research, including operation of the wet lab and feeding protocols for BC.

   - **local capacity strengthening** – Fisheries communities in the Sre Ambel River activity area were empowered 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.
   - **digital** – Teams recorded video clips on fish processing methods such as smoking, nutritional sampling and preparation methods, and sensory techniques.
   - **youth engagement** – 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.
   - In FY23, teams will complete wet lab installation and training plans for partners, farmers, and fishers on its operation and complete feed formulation research as well as continue fisheries harvest data collection and processing, while discussing sustainability plans and transfer of technologies.

   In-Country Contact Information: Som Sitha, ssom@wcs.org, Wildlife Conservation Society (WCS); Simon Mahood, smahood@wcs.org, WCS; Lyda Hok, hoklyda@gmail.com, Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture.

   In-Country Partner Organizations: Wildlife Conservation Society, Phnom Penh, Cambodia; Sre Ambel Community Fisheries Council; Center of Excellence on Sustainable Agricultural Intensification and Nutrition, Royal University of Agriculture.

7. **Bangladesh:** The Fish Innovation Lab has five research activities in Bangladesh, working to establish genetically improved carp strains and conduct field trials; develop and disseminate technology for cryogenic sperm banking of carps; identify major sources of microbial pathogens in pangas and tilapia value-chains; analyze the economics of aquaculture value-

chain; and harness machine learning to estimate aquaculture production and value-chain performance. These activities feed into the lab's goal to alleviate poverty and improve nutrition through reliable provision of fish. In FY22, fish harvested from farm trials of genetically improved rohu carp weighed 37% more than unimproved carp; breeding of six carp species in hatcheries in four regions using cryopreserved sperm produced seeds stocked in 13 hatcheries for brood production; and seeds from cryopreserved sperm grew bigger than seeds from sperm of hatchery-origin males. Teams determined prevalence of major foodborne pathogens on pangas and tilapia at markets and identified practices associated with increased microbial contamination; surveyed 820 farmers to assess the status of aquaculture value-chains and published four articles (1, 2, 3, 4); published two papers on fishpond detection using machine learning (1, 2); and completed three workshops on machine learning for 146 government, non-profit, and private sector participants.

- **local capacity strengthening** – The Department of Fisheries applied training to respond to consumer demand for genetic detection of major foodborne pathogens for the first time and expressed interest in using other Fish Innovation Lab innovations (e.g., machine learning approach to estimating aquaculture production and obtaining improved carp brood stock).
- **youth engagement** – Teams conducted nine trainings on sperm cryopreservation for 225 hatchery and nursery operators, fish farmers, and academics in four regions who were 40% youth and 30% female.
- **private sector engagement** – Seven commercial hatcheries sold 245 kilograms of genetically improved rohu carp spawn at more than double the price of unimproved spawn. Thirty commercial hatcheries now have improved brood stock, substantially increasing availability of this product to nurseries and farmers.
- **digital** –Teams trained 136 participants online on remote sensing for fishpond identification and produced 13 videos on innovative practices in aquaculture reaching 10,107 people on Facebook and YouTube.
- In FY23, teams will participate in academic conferences (e.g., World Aquaculture Society), lead stakeholder workshops, and continue publication efforts.

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

A summary of the FY 22 accomplishments per country and Fish Innovation Lab indicator is presented in Table 1. A full list of indicator results is shown in Appendix 2. Three Fish Innovation Lab success stories are presented in Appendix 3.

Table 1: Summary of FY 22 Country Accomplishments

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	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**	**Ghana**
Sex								
Male	320	1,316	682	181	113	269	46	25
Female	115	895	249	40	105	241	240	20
Disaggregation not available	0	0	0	0	0	0	0	0
Totals	**435**	**2,211**	**931**	**221**	**218**	**510**	**286**	**45**

EG.3-2: Number of individuals participating in USG food security programs								
EG.3-2: Other project participants	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**	**Ghana**
Gender								
Male	480	2,131	191	1,208	155	521	26	30
Female	221	2,050	124	102	134	1,506	163	21
Totals	**701**	**4,181**	**315**	**1,310**	**289**	**2,027**	**189**	**51**
Age								
15-29	194	1,302	13	217	37	912	113	10
30+	507	2,584	142	1,093	166	1,080	72	31
Disaggregation not available	0	295	160	0	86	35	4	10
Totals	**701**	**4,181**	**315**	**1,310**	**289**	**2,027**	**189**	**51**

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	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**
Status							
Phase 1: Under Research	2	5	1	3	1	0	0
Phase 2: Under Field Testing	1	3	1	2	0	0	0
Phase 3: Made Available for Transfer	0	0	0	0	0	0	0
Phase 4: Demonstrated uptake by the public and/or private sector	0	0	0	0	0	0	0
Totals	**3**	**8**	**2**	**5**	**1**	**0**	**0**

EG.3.2-7: Production Systems Research	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**
Status							
Phase 1: Under Research	0	5	1	2	1	0	1

Phase 2: Under Field Testing	6	8	5	0	1	2	0
Phase 3: Made Available for Transfer	3	14	12	0	2	0	0
Phase 4: Demonstrated uptake by the public and/or private sector	1	0	0	0	0	0	0
Totals	**10**	**27**	**18**	**2**	**4**	**2**	**1**

EG.3.2-7: Social Science Research	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**
Status							
Phase 1: Under Research	0	7	2	3	0	0	2
Phase 2: Under Field Testing	2	3	1	0	0	1	1
Phase 3: Made Available for Transfer	3	3	1	2	0	0	0
Phase 4: Demonstrated uptake by the public and/or private sector	0	1	1	0	0	0	0
Totals	**5**	**14**	**5**	**5**	**0**	**1**	**3**

EG.3.2-24: Number of individuals in the agri-food system who have applied improved management practices or technologies with USG assistance							
EG.3.2-24: Applied Tech	**2022 Target**	**2022 Actual**	**Nigeria**	**Bangladesh**	**Cambodia**	**Kenya**	**Zambia**
Gender							
Male	15,000	1,031	410	59	75	316	171
Female	5,213	472	288	2	57	21	104
Not Applicable		270	0	0	0	0	270
Totals	**20,213**	**1,773**	**698**	**61**	**132**	**337**	**545**
Age							
15-29	5,000	326	95	6	7	55	163
30+	12,000	1,274	603	55	97	282	237
Not Applicable	3,213	173	0	0	28	0	145
Totals	**20,213**	**1,773**	**698**	**61**	**132**	**337**	**545**

*Includes number of individuals trained

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, the Fish Innovation Lab supports research and capacity-building activities targeting three program areas:

1. **Advancing productivity:** The Fish Innovation Lab works 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 includes developing innovations to increase achieved yield of fish in aquaculture, improving availability and nutritional quality of feed (especially removal of fish

meal 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 identify and develop scalable technologies and practices that promote resilience and mitigate food security risks, especially through improved fish and environmental health. This includes 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 generates evidence on how to sustainably and equitably improve economic opportunity, nutrition, and resilience in aquaculture and fisheries value chains, households, and communities. This includes 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 provided 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, and 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 in developing countries, 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.

Fish Innovation Lab strategies are 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 theory of change posits that: ***If*** innovative technologies from universities and nongovernmental organizations (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 activities connect to this theory of change and include three approaches, as specified in the Fish Innovation Lab 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. The Fish Innovation Lab ME will implement activities that align to 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 align with Fish Innovation Lab's three areas of inquiry, which are the focus of the Fish Innovation Lab research for development and capacity building programs. The activities undertaken within these objectives were implemented in four phases:

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

Research Strategy Development

The Fish Innovation Lab research strategy provides a framework for the cumulative contributions of the diverse set of research activities currently being implemented. The research strategy will enable the ME and ME Partners to leverage the potential for comparative analysis between country contexts. It will also help 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 (cross-cutting theme leaders and regional leaders) 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 are 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)*

In FY22, activities that address the research strategy questions across teams and countries included:

- Fish Innovation Lab nutrition specialist Dr. 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 Dr. Shakuntala Haraksingh Thilsted gave opening remarks. The event highlighted four research activities from the Fish Innovation Lab that are testing 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, Cultivating Equality: Advancing Gender Research in Agriculture and Food Systems. Gender and youth equity specialists, Drs. 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." Drs. Seth Adu-Afarwuah and Brietta Oaks, PIs of the project 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 Feed the Future Innovation Lab for Fish 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).

Research Activity Reports

Objective 1: Advance aquaculture and fisheries productivity

Activity 1.1: Aquaculture and rural communities: Farm diversification strategy through integrated agriculture-aquaculture systems and nutrition-sensitive value chains for better nutrition outcomes (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
Host Country (HC) PI: E.K. Ajani, PhD, University of Ibadan
HC Co-PI: B.O. Omitoyin, PhD, University of Ibadan

Objectives: The activity goal is 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 for future needs of vulnerable populations will be addressed through appropriate research and targeted interventions. The activity will 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 are:

1. The activity will 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. The activity will 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. The activity will study value chain enhancement through market access facilitation and marketing management.
4. The activity will 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.

Outcomes:

1. Suitable integrated rice-fish production technology will be developed through participatory research actions.
2. Understanding of convenient market access approaches and nutrition contributions of rice-fish farming products will be achieved.
3. Capacity development and enhancement of co-learning among all stakeholders (farmers, value-chain actors, and extension workers) will be accomplished.

Achievements: In FY22, the team developed a rice-fish production training manual and conducted a training on appropriate farm record keeping. The team initiated the second cycle of rice-fish farming that incorporated adaptation to the challenges observed during the first cycle of production.

The adaptations included: covering the field with net to prevent predation from birds, incorporating trainings on fish seed production to address the challenges of fish seed availability, removal of plastic lining from the trenches, and training on black soldier fly (BSF) production as an additional fish feed source.

The team conducted fish feed research, which was expanded to include small-scale BSF larvae production and the use of locally available raw materials (rice bran, fish offals) in the development of fish feed. A case study example (step by step process) of rice field adaptation to include fish production was developed. The case study can be replicated in any sub-Saharan African country or adapted to local conditions of new areas.

Lessons learned: During this time period, the team found that water availability based on season (wet or dry) is crucial to the success of rice-fish farming and encouraged rice-fish farming during the rainy/wet season. The team is introducing trainings in fish breeding and in production of low-cost BSF technology. These will address issues related to limited access to fish seed and feed. The team is also developing combinations of local feed ingredients (rice bran, fish offals) for local feed production. The size of fish stocked should be considered in terms of the expected harvest size of fish and to prevent fish loss from predatory birds. A net cover of the field or the stocking of larger fish would help to mitigate this challenge. Smoking harvested fish instead of selling them fresh would improve market competitiveness. The team encouraged smoking of the fish due to their size at harvest after 3-4 months of co-culture with rice. The cultured fish cannot compete with the larger, commercial fish available in the fresh fish market.

Presentations and publications:

Burtle, G. J. 2021. “Feeding Fish in Rice-Fish Systems.” Presentation, University of Ibadan, Nigeria, August 2021.

Fonsah, E. 2021. “Revolutionizing Agriculture in Africa.” Presentation, University of Ibadan, Nigeria, August 2021.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Chemical Evaluations of Agricultural Wastes from Integrated Fish and Rice Farming and Their Potential as Fish Feed Ingredient.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Evaluation of Water Quality and Soil Properties of Integrated Rice and Fish Farming, IRF System Under Different Agro-Ecological Zones in Nigeria.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Fish Bioenergetics: A Model for Calculating Consumption and Growth of Fish in Integrated Rice and Fish Farming.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Nutrients, Water Primary Productivity, Plankton and Macro-Invertebrates Diversity of Integrated Aquaculture Rice and Fish Farming in Nigeria.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Rice and Fish Yield Optimization Under Integrated Aquaculture and Agriculture.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

Halwart, M., Ajani, E. K., Bart, A., Ajayi, O., Burtle, G. J. 2022. “Water Utilization, Nutrient Assessment and Water Quality Performance Under Integration of Rice and Fish.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, U.S.A., August 2022.

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 will evaluate integrated insect-to-fish farming systems: 1) costs and conversion ratios of propagating black soldier fly (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 BSF meal replacement in fish feed; 4) changes in nutrient profiles of farmed fish resulting from partial BSF meal substitution in fish feed; 5) economic viability and impacts of female-led small-scale BSF production enterprises; and 6) effects of BSF meal production and processing on labor, time allocation, and household income for the BSF farmers and fish farmers. The team expects fish farmers to willingly learn about and adopt BSF meal because it is a low-cost, local-input, non-mechanized technology that will produce a substantial part of the animal protein needs of fish.

Outcomes: These activities are expected to produce the following evidence and service delivery: 1) BSF-based aquaculture feed will be developed that is noncompetitive with human food production to improve sustainability of the aquaculture industry; and 2) capacity of private sector, academic, and NGO stakeholders will be enhanced via training seminars and workshops. Ultimately, achievement of these outcomes should result in increased food and job security for vulnerable populations in Nigeria.

Achievements: During FY22, the team reorganized project activities to address implementation challenges. The team decided to compound the feed to be used for the research demonstration plots in Oyo State and decided to outsource the BSF larvae meal used in feed compounding. The team agreed that all other materials needed for the study such as catfish juveniles be sourced from Ibadan to ensure good quality fish seed. Tanks for demonstration plots of 0% BSF larvae meal and 30% BSF larvae meal fish feed were moved from Ibadan to Ebonyi and Cross River States and installed. The tanks for demonstration plots in Oyo State were also installed using two local government areas as study sites. Production of the experimental feeds was completed, and they will be moved to the sites by the first week of October 2022. Catfish juveniles to be used for the demonstration plots will be moved with the feed. The team continued to collaborate with the integrated rice-fish activity in Ebonyi State on the potential for reducing the cost of fish feed using the BSF larvae meal. Once the demonstration plots are established in October 2022, baseline data collection will begin using enumerators the team has identified. Feed has been set aside for microbial analysis.

Lessons learned: Many farmers who reduced or left fish production are eager to return with the prospect that the BSF larvae meal could reduce feed costs. With reduced cost of fish feed, farmers could potentially produce fish at a lower cost. The delay that the team experienced was due to logistic challenges faced in moving materials from one region of the country to another when it was discovered that feed compounding mills and other supplies were not readily available in the target zones.

Presentations and publications:

Bennett, A. 2022. "Por que integrar la pesca en la agenda de sisteas alimentarios?" Presentation, Del Mar a la Mesa: Pesca y sistemas alimentarios sostenibles en Mexico, Mexico, September 2022.

Omonona, B. T., Pechal, J. L., Valle de Souza, S., Adedeji, O. B., Bennett, A., Benbow, M. 2022. "Piloting Insect-to-Fish Farming Systems in Nigeria." Presentation, 4th Insects to Feed the World, Québec, Canada, June 2022.

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 is 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 is to explore how Lean technology can be used in a developing 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. In short, the goal is to prevent the loss of value along the value chain and economize the process of raising fish and bringing them to market using Lean technology.

Outcomes: Tilapia and catfish industries in Ogun and Delta states of Nigeria will adopt and apply science-based Lean production system management concepts to increase efficiency by reducing production costs, waste, and postharvest losses. Application of these strategies will increase financial and social benefits to small-scale farmers and their families. If successful, the activity will implement a scaling program to drive down the costs of production within the sector, which has potential to decrease costs to consumers.

Achievements: This activity is applying Lean management practices and Lean tools to increase fish farm and fish processing efficiency. This in turn will increase the productivity and availability of fish in the local markets. Trained Lean Subject Matter Experts (LSMEs) worked in partnership with fellow farms and processors for this technology adoption. Thus far, 40 LSMEs have engaged 219 farms to identify and reduce waste streams to improve farm efficiency by applying Lean management tools. In total, data from 602 actions of 219 mini projects to reduce waste streams have been submitted to calculate percentage efficiencies. Of the completed 219 mini projects, 11.1% were on reduction in mortality, 10.1% on reduction in energy use, 8.1% on reduction in use of labor, and 7.0% on reduction in feed cost.

Lessons learned: The team learned that well organized and executed virtual platforms allowed for a more efficient implementation of the projects.

Presentations and publications: None to report.

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 (RUA)
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 is to develop and apply new technologies on formulated sustainable feeds for bighead catfish (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 are:

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.

Outcomes:

1. Sustainable fish culture technology to meet increasing demand of local catfish (*Clarias macrocephalus*) for local and regional markets will be developed.
2. The overfishing of local catfish (*Clarias macrocephalus*) and the use of underrated fish in BC feed will be reduced.
3. Knowledge and human capacity on aquaculture in Cambodia will be improved.

Achievements: In FY22, three RUA personnel, the Project Coordinator, and two Graduate Research Assistants improved their knowledge and capacity on scientific aquaculture research and on the operation of a wet lab including pelleted sinking feed formulation, preparation, and data management. The wet lab installation was 80% complete at the time of reporting. Development of formulated feed for bighead catfish based on soybean meal and feeding protocols are in process.

Through in-person and virtual meetings, partnership was maintained with the faculty of fisheries, WorldFish, and other relevant partners. The team recruited four undergraduate research assistants who will engage with the research activities.

Lessons learned: 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.

Presentations and publications: None to report.

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.

Outcomes:

1. Estimations of sustainable yields specific for coral reefs at activity sites will be determined, and community knowledge will be improved.
2. The best metric for estimation of sustainability of fisheries will be determined, and community knowledge will be improved.
3. Community capacity will be improved through training in monitoring coral reef fisheries and ecology.
4. Perception by communities of resource use and sustainability will be changed, resulting in improved management practices.

Achievements: An independent stock assessment indicated that current maximum sustainable yields for Shimoni-Vanga seascape were at 3.8 tons/km2/year for total biomass and 2.98 tons/km2/year for fishable biomass. The stock assessment registered lower stocks than other studied sites in Kenya, which had 6 tons/km2/year. The lower stocks indicate fisheries have low production, which directly affects the resource sustainability and capacity to meet the social well-being needs of resource users. The dependent stock assessment showed a yield between 1-1.5 tons/km2/year for the Shimoni-Vanga seascape indicating that communities lose about half of the stocks yearly, directly affecting their social-wellbeing and food security. Further results showed the communities lose on average between $537-$643USD/km2/year. Based on findings, the current status of the resources and perceived economic loss pose a concern for resource users and managers in ensuring stocks are replenished and can sustainably meet community members' present and future needs.

The team conducted community training on fish biomass assessments that enabled individual members of the communities to gain knowledge of fish biomass and yield status in Kenyan coral reefs. The participants learned to undertake an underwater visual census of fish in coral reefs, data entry, and interpretation of biomass and yield data in their respective fishing areas. The training also improved communities' knowledge of the 19 common fish families found within their region, as well as fish family identification, and enhanced their skills in swimming and diving. This led to development of a fish biomass training manual, which is currently used by community data collectors as a reference tool for recording landed fish. An additional two community members now assist with data collection in Mkwiro and Vanga sites, increasing the number who can use the Atlan Collect application in data collection.

Lessons learned: The study evaluating whether communities could monitor their own resources through a comparison of trained fisheries staff and community members' collected data showed that communities are able to conduct successful monitoring. This finding resulted in a change of roles of fisheries officers from recording fish weights to recording fish length. Trained community members, through this program, have been hired by Non-Governmental Organizations (NGOs) while others are working with the Fisheries Department through Beach Management Units (BMUs). There is an ongoing transfer of skills through community efforts in specific communities. This gives the communities the right skills to be employable as well as monitor their own resources when the Fish Innovation Lab-funded activity closes.

Presentations and publications:

McClanahan, T. R., Kosgei, J. K., Oddenyo, R. “Status of the Fisheries Resources in Shimoni-Vanga Seascape.”

McClanahan, T. R., Kosgei, J. K., Oddenyo, R. “Stock Assessment Protocol.”

Activity 1.6: Cryogenic sperm banking of Indian major carps (*Labeo catla*, *Labeo rohita*, and *Cirrhinus cirrhosis*) and exotic carps (*Hypophthalmichthys molitrix*, *Hypophthalmicthys nobilis*, and *Ctenopharyngodon idella*) 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 is 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 are:

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.

Outcomes:

1. Donor broodstocks (male and female) of IMCs from different river origins and three exotic carps will be developed.
2. Sperm of IMCs and exotic carps will be cryopreserved, and a cryogenic sperm bank will be developed.
3. Seeds of IMCs and exotic carps in public and private hatcheries using cryopreserved sperm will be produced, and quality will be characterized and assessed through growth studies and DNA microsatellite markers.
4. Performance of cryopreserved sperm will be assessed, and the feasibility of establishing sperm banks in additional regions will be evaluated.
5. Seeds produced with cryopreserved sperm will be supplied to 24 hatcheries (technology adoption) beyond the 22 selected (pioneer) hatcheries in four regions, and the growth and survivability of the seeds will be compared.

Achievements: In FY22, sperm of all six fish species (rohu, catla, mrigal, silver carp, bighead carp, and grass carp) were cryopreserved, and the team developed cryogenic sperm banks. The team developed a standardization for basic parameters of cryopreservation protocols of the species. The team conducted breeding of all six species in 22 public and private hatcheries in Mymensingh, Faridpur, Jashore, and Barishal regions using cryopreserved sperm. In addition, seeds of each species were produced in 17 hatcheries, which were then stocked in 13 respective hatcheries, four technology adoption hatcheries, and fish farms in four regions. They are being reared along with controls in separate nursery ponds with supplementary feeds. The team began the sampling of cryopreserved sperm seeds and fresh sperm-origin seeds. Genetic characterization of broodstocks using DNA microsatellite markers was conducted.

The activity trained a total of 400 stakeholders (hatchery, nursery operators, and fish farmers) who participated in training workshops in Jashore, Barisal, Faridpur, and Mymensingh regions; among them 30% were women and 70% were males. Among the males, 40% were youth. The Fish Innovation Lab conducted a Bangladesh Aquaculture Sector meeting in July where the activity outputs were presented. Two MS students completed their MS degree and four new MS students, including two females, were recruited.

Lessons learned: During the reporting period, seeds of all six species in 17 hatcheries were produced, proving that seed production using cryopreserved sperm is possible at the field level. The team conducted training workshops on dissemination of sperm cryopreservation technology for hatchery operators, nursery operators, and fish farmers in four regions as well as for MS, PhD students, and junior faculty members in Mymensingh. Training activities inspired the trainees to use the cryopreservation technology in seed production, and many of them participated in the research program. Similarly, the nursery operators and fish farmers expressed their willingness to work with the technology. If hands-on training for more stakeholders can be arranged, it is likely that more hatchery, nursery operators, and fish farmers will come forward and adopt the cryopreservation technology in their breeding facilities.

Presentations and publications:

Ferdous, A. 2022. “Cryopreservation of Sperm of Bighead Carp (*Hypophthalmichthys nobilis*, Richardson) and Production of Seeds Using Cryopreserved Sperm in Selected Hatcheries.” Presentation, Bangladesh Agricultural University, Bangladesh, March 31, 2022.

Mollah, A. 2022. “Cryopreservation of Sperm of Silver Carp (*Hypophthalmichthys molitrix*) and Production of Seeds Using Cryopreserved Sperm in Selected Hatcheries.” Bangladesh Agricultural University, Bangladesh, March 31, 2022.

Mridha, M. U. 2021. “Standardization of Cryopreservation Protocol of Rohu (*Labeo rohita*, Hamilton) and Production of Seeds Using Cryopreserved Sperm in Selected Hatcheries.” Presentation, Bangladesh Agricultural University, Bangladesh, December 31, 2021.

Sarder, R. I., Rahman, M. M., Bau, M. 2022. “Cryogenic Sperm Banking of Indian Major Carps (*Catla catla, Labeo rohita* and *Cirrhinus cirrhosus*) and Exotic Carps (H*ypophthalmichthys molitrix, Hypophthalmichthys nobilis* and *Ctenopharyngodon idella*) for Commercial Seed Production and Brood Banking.” Presentation, Feed the Future Innovation Lab for Fish Bangladesh Sector Meeting 2022, Syed Nazrul Islam Auditorium, BAU, Mymensingh, Bangladesh, July 2022.

Sarder, R. I., Tiersch, T., Rahman, M. M., Razzak, A., Alam, M., Hossian, S., Bau, M. 2022. “Cryogenic Sperm Banking of Mrigal (*Cirrhinus cirrhosus*) and Production of Seeds in Commercial Hatcheries.” Presentation, 9th Biennial Conference & Research Fair 2022, BARC Auditorium, Bangladesh, May 2022.

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, MS, 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.

Outcomes:

1. Community and regional knowledge of fisheries management and postharvest food processing techniques will be increased in youth, women, and men.
2. A long-term dataset will be developed on artisanal fisheries diversity, abundance, size distributions, and reproductive stage, which will inform ongoing and future community-based management efforts.
3. Training of villagers in fisheries data collection and analysis will be done, which will allow successful transfer of the program to the Community Fisheries Council upon activity completion.
4. Postharvest training will be provided, which will add capacity to develop fish processing and preservation techniques for family-scale to village-scale fish handling.

Achievements: To accomplish Objective 1, the Citizen Science program continued to support 15 fishers, including one woman, from four villages along the Sre Ambel River. Most of these fishers depend primarily on fishing for their livelihoods and family nutrition. These fishers completed 18 months of data collection on their harvest. The fishers recorded individual-level data resulting in >32,433 entries for >52,300 individual fish harvested. Data collection was done in collaboration with

the local partner, the Wildlife Conservation Society (WCS). In collaboration with the Cambodian Fisheries Administration, a senior ichthyologist trained WCS staff on taxonomic identification. This training allowed the team to train the fishers resulting in reduced misidentifications, thus enhancing data quality. Co-PIs from MSU observed this improved data quality during a recent trip to Cambodia. The team visited fishers and were pleasantly surprised by the precision in data collection and application of the protocol by the fishers. The team gave a seminar and conducted two workshops to share results and discuss strategies for the last year of the program. The fully functional iFISH data visualization app was demonstrated to stakeholders. One graduate student is analyzing part of the data for his MS thesis.

To satisfy Objective 2, the team completed the fishermen surveys and sensory panels in seven Cambodian communities. Team members organized and evaluated the data for submission of an abstract. Samples collected for nutritional analysis were brought to the United States for proximate and fatty acid analysis.

Lessons learned: Field visits to fishers participating in the Citizen Science program confirmed that good communication and strong participant commitment lead to robust baseline data. The team discovered that for the tasks under Objective 2, it was challenging to invite participants who did not participate in data collection for Objective 1. To reach 100 targeted participants for the survey, the team conducted on-site interviews with fishermen along the Sre Ambel river and allowed market fish vendors to participate. The survey with fishermen was mostly conducted in the early morning when they were catching fish and the weather was pleasant enough for interviews. No more than six surveys were conducted daily, making this a very time-consuming process. For sensory panels, the team cooked eight samples and served them to consumers. Due to the small number of participants per panel, the travel was intensive. Sample preparation for the chemical analysis was conducted by graduate students at MSU, who recorded and added captions to facilitate remote learning of sample preparation methods.

Presentations and publications:

Allen, P., Sitha, S., Correa, S. B., Neal, J., Yon, T. 2022. “Using Citizen Science to Overcome Data Gaps in Artisanal Fisheries.” Presentation, 152nd Annual Meeting, American Fisheries Society, Spokane, Washington, U.S.A., August 2022.

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.

Outcomes:

1. Partner hatcheries and nurseries will have improved capacity for management of carp genetics and improved carps for optimal impact.

2. Pond productivity will be improved, and farmers' incomes will be increased through adoption of genetically improved rohu. Documentation of the substantial gains in growth will also provide a powerful marketing tool for dissemination at scale by private sector hatcheries.
3. Long-term genetic management of carp in commercial hatchery operations will be based on fully pedigreed and genetically diverse carp breeding populations with increased growth rate, and management will be supported by adoption of pedigree assignment and cryopreservation methods.

Achievements: With the support of the Fish Innovation Lab and other funders, all fish from the on-farm performance trials of Generation 3 (G3) rohu were harvested and assessed. The team discovered that G3 outperformed other treatments at all 19 farms, and overall G3 fish weighed ~37% more than fish from the unimproved rohu strain at harvest. The team presented the results at conferences, workshops, and seminars and promoted them in the Bangladesh media. Spawn sales of WorldFish G3 rohu by commercial hatcheries in 2022 amounted to 245 kg (i.e. equating to approximately 100 million eggs) from the seven commercial hatcheries that spawned G3 broodstock in 2022. The team is continuing to monitor the sales of G3 rohu to nurseries and farmers. Hatcheries sold G3 spawn at a substantial premium to unimproved spawn (i.e. more than double the price).

The 2020 G3 rohu grow-out trials were completed in late 2021, and the top ~20% of fish from each 2020 G3 rohu family were retained as candidate parents of G4. The team completed tagging of 2021 G1 catla (120 families) and 2021 G3 rohu (215) and are continuing the grow-out trials of these families. The 2022 G2 silver carp (240) and 2022 G1 catla (81) families were generated and nursed. Tagging of 2022 G2 silver carp has commenced ahead of schedule. Representative families of G3 rohu (2 sites), G1 catla (2 sites), and G1 silver carp (1 site) were sent to external backup site(s).

The team completed the genotyping of samples and have begun the data analysis and manuscript preparation.

Lessons learned: The main challenges the team faced were related to the ongoing impact of COVID 19 delays (e.g. Rohu SNP genotyping and analysis) and a lack of human and financial resources to implement the business plan.

Presentations and publications:

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. 2022. "On-farm Trials of WorldFish Genetically Improved Rohu." Book of Abstracts, 2nd International Conference on Sustainable Fisheries (ed. by ICSF), p. 70. Faculty of Fisheries, Sylhet Agricultural University, Sylhet, Bangladesh, 2022.

Activity 1.9: 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: Black soldier fly (BSF) farming represents a viable option for enhancing productivity of aquaculture value chains in Malawi. This activity's focus on fish feed production will 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 fish meal 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 is 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. To achieve this goal, the activity will 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 will 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.

Outcomes: These activities will lead to the following changes:

1. Defining a low-input system to increase production of BSF-meal and related products (e.g., compost).
2. Creation of three small-scale BSF farms led by women and youth to produce BSF larvae meal for both domestic use and commercialization as fish meal replacement in aquaculture operations.
3. Development of insect farms to work in synchrony with local fish farmer volunteers (e.g., collaboration with the Farmer-to-Farmer program) to teach the community how to mass rear BSF.
4. Establishment of collaborations between fish and insect farmers by integrating BSF larvae meal to replace current fish meal used in fish feed.

Achievements: None to report.

Lessons learned: Despite continuous efforts from the Management Entity 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.

Presentations and publications: None to report.

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-Debouteville, 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: Olusola Bodunde, MS, 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 (BMPs) 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.

Outcomes:

1. Risk factors for disease emergence, outbreaks, and spread, including seasonality issues with respect to environmental and climate change associated risks, will be identified.
2. Endemic, emerging, and exotic pathogens will be identified, and economic impacts will be quantified in regional models.
3. Whole genomes of key pathogens isolated from farming systems and seed supply networks will be sequenced by next generation sequencing.
4. Health management interventions for fish farming systems and fish seed supply chains that reduce fish disease risks, in the form of BMPs and capacity building activities tailored to the needs of various stakeholders, will be developed and implemented.
5. Research findings and capacity development activities will support development and operationalization of a simple and practical national aquatic animal health and biosecurity strategy for implementation by the national competent authorities.

Achievements: In FY22, video conferencing equipment was installed at the University of Ibadan (UI), and the system was used regularly for meetings between the UI team with MSU and WorldFish colleagues to discuss progress on project milestones and planning. The team completed the data cleaning of the epidemiology survey and conducted descriptive statistics on the data. Hematology and biochemical analysis from the rainy season sampling campaign was completed. The team collected new samples from fish with clinical signs during this year's dry season. Bacteriology yielded over 400 bacterial isolates including *Aeromonas, Edwardsiella, Flavobacterium, Pseudomonas,* and *Vibrio.* Histology slide reading is ongoing with focus on lesioned organs. The team completed the dry season sampling in both Delta and Ogun States. The Resident Aquatic Veterinarian (AquaVet) Network was established. UI launched the E-AquaHealth diagnostic extension service platform in August. A web-based GIS map to display data from the fish epidemiology and health economics survey is under development. The team led a webinar co-hosted by the Fish Innovation Lab and Aquaculture Africa Magazine (AAM) and presented project findings to stakeholders through a workshop. In addition, the team organized a focus group for discussion on best management practices and a scoping group focused on a National Aquatic Animal Health Strategy; draft findings from both were produced. The team conducted a training on bacterial DNA extraction and bacteriology methods.

Lessons learned: The WorldFish and MSU activity partners acknowledged the real value of face-to-face interactions with partners in Nigeria during a visit to Ibadan. Being able to visit the field and lab facilities gave a better understanding of the reality and limitations. The value of IITA in providing access to their service facilities (e.g. microbiology lab unit) to complete some of the project laboratory activities (DNA extraction, quantification, PCR, Sanger sequencing) was recognized.

Presentations and publications:

Adeyemo, O. K., Chadag, M., Hanson, L. A., Delamare-Debouteville, J. L. F., Bodunde, O. A., Khor, L. 2022. “Improving Biosecurity and Managing Catfish and Tilapia Diseases in Nigeria

Aquaculture." Presentation, Feed the Future Innovation Lab for Fish webinar series by Aquaculture Africa Magazine, Online, July 2022.

Adeyemo, O. K., Ogundijo, O. A., Alarape, S. A., Adetunji, V. E., Adedeji, O. B. 2022. "Roles of Faculty of Veterinary Medicine in Aquatic Medical Training and Research in Nigeria: A Case Study of University of Ibadan." Presentation, Aquaculture Africa 2021, Bibliotheca Alexandrina, Alexandria, Egypt, March 2022.

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 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.

Outcomes: This study will provide data on microbiological quality of fish at retail markets and along the supply chain. The study will provide an understanding of how behavioral practices among different value-chain actors impact the load of microbial pathogens on fish and the key players to train in a future intervention study. Results and data from this study will support science-based decisions on the most effective methods and key actors/locations where interventions can reduce microbial contamination of fish in informal markets of Bangladesh. Training of local laboratories on microbial methods and risk analysis will be useful not only for this study but for expanded monitoring of the microbial quality of fish at sale.

Achievements: In FY22, the team determined the prevalence of major foodborne pathogens on pangas and tilapia fish at the wet markets and super shops in Dhaka city. In addition, the team identified market practices and conditions associated with increased microbial contamination of fish. Sample collection from these markets was completed to achieve the target number of samples with the remaining 84 samples from retail markets and 24 samples from super shops. Samples were tested for *E. coli*, ESBL-producing *E. coli, Salmonella* spp., *Vibrio cholerae, Vibrio parahaemolyticus, Shigella* spp., and *Cryptosporidium* spp.

The activity team completed the antibiotic susceptibility testing of 458 *E. coli* including 239 ESBL producing *E. coli,* 121 *Salmonella* spp., and 298 *Vibrio cholerae* against a panel of clinically important antibiotics identified in the Clinical and Laboratory Standard Institute Guidelines from the first phase. The team tested all 458 *E. coli* isolates from the first phase for pathogenic genes by PCR, compiled the results and findings, and presented them at the annual meeting of the International Association for Food Protection (IAFP).

The team began collection of whole fish, ice/water, and swab samples from fish cut-up boards from retail, wholesale markets, and grower ponds as a part of the phase two activities. The team collected 452 samples from 10 retail markets, 5 wholesale markets, and 6 grower ponds. Among these samples, 280 samples were from retail markets including 108 from whole fish, 84 from cut-up

boards, and 88 from water in fish tanks. In addition, the team collected 100 whole fish from 5 wholesale markets and 60 whole fish and 12 water samples from 6 grower ponds. The team tested samples for *E. coli*, ESBL-*E. coli*, *Salmonella* spp., and *Vibrio cholerae*. Also, during this period, the activity provided hands-on short-term and follow-up training to the staff from the Department of Fisheries and enrolled two MSc students from the department of Fisheries, Dhaka University as a part of long-term training.

Lessons learned: The team faced challenges due to the ongoing COVID-19 pandemic. Both sample collection and laboratory operations were interrupted repeatedly and substantially, slowing down progress on achieving targets. An additional challenge was optimization of the method for detection and identification of *Cryptosporidium* spp. from fish samples. It took some time to optimize the technique, which also slowed down the flow of sampling. The team ramped up the sampling process when the pandemic situation in Bangladesh improved, compensating for this delay. Finally, during the sector meeting in Mymensingh this year, stakeholders provided feedback on the term "fecal pathogen" used in the project. 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.

Presentations and publications:

Amin, M.B., Hossian, M. I., Roy, S., Saha, S. R., Islam, M. R., Mahmud, Z. H., Islam, M. S., Narrod, C., Parveen, S., Islam, M. A. "Assessment of Fresh Fish in Retail Markets for Contamination with Major Fecal Pathogens and Antibiotic Resistant Organisms." Abstract, Annual meeting of International Association of Food Protection (IAFP), Pittsburg, U.S.A., July 31-August 3, 2022.

Parveen, S. 2022. "An overview of Food Safety System in Bangladesh." Presentation, International Association for Food Protection (IAFP) Annual meeting, Pittsburgh, Pennsylvania, August 2022.

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 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, BVM, Zambia Ministry of Fisheries and Livestock

Objectives:

1. Identify *Lactococcus garviae, Streptococcus iniae, Streptococcus agalactiae, Aeromonas hydrophila*, and *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 the *L. garviae*, *S. iniae*, and/or *S. agalactiae*.
4. Devise methods of administering autogenous vaccines to the fish on the farms.
5. Improve the administration of the already developed *L. garviae* vaccine through various methods.

Outcomes:

1. Characterization of pathogenic bacteria responsible for fish mortalities.
2. Development of environmentally friendly vaccines leading to a decreased need to use antimicrobials and chemical treatments.

3. Adoption of improved methods to administer fish vaccines.
4. Reduction of stress during handling of fish.

Achievements: The team initiated the project's core activities as they collected fish samples. This activity facilitated interaction with fish farmers and enabled the team to gain an understanding of the situation experienced by fish farmers in real time. The farmers ask aquatic health related questions and share their problems with the team. This has provided a platform where farmers learn as the team collect samples. The team collected sick fish from the small-scale fish farmers involved in cage farming. In preparation for infection experiments, investigators refurbished the wet laboratory and stocked animals for experimentation. Challenge studies can now be conducted concurrently with vaccine trials.

The key elements of identifying and isolating bacteria have been done, including phenotypic and genotypic identification. The genotypic identification involved polymerase chain reaction and sequencing of the amplified 16S rRNA product. The team was then able to identify a number of microorganisms associated with diseased fish. Work is ongoing for vaccine development following identification of the bacteria.

As project activities are undertaken, postgraduate students and fisheries extension staff are benefitting from the exposure to fish sampling, sample collection, and packaging of fish samples. The students and field teams have also been exposed to humane fish handling. Two MS students and one PhD student were recruited to undertake the core activities of the program. The students completed their proposals, and the University approved them.

Lessons learned: The team had to make adjustments such as direct engagement of concerned principal officers due to delays in the processes of implementing activities emanating from bureaucratic institutional arrangements.

Presentations and publications:

Hangombe, B. 2022. "Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia." Presentation, Feed the Future Innovation Lab for Fish Virtual Annual Meeting, Mississippi State University, U.S.A., August 2022.

Hangombe, B., Changula, K., Songe, M., & Namangala, B. 2022. "Protective and Antibody Reactivity in *Oreochromis niloticus* Following Vaccination Using an Experimentally Produced Autogenous Polyvalent Vaccine of Commonly Associated Bacterial Pathogens in the Aquaculture Environment on Lake Kariba." Presentation, Feed the Future Innovation Lab for Fish Virtual Annual Meeting, Mississippi State University, U.S.A., August 2022.

Zulu, F., Reichley, S., Siamunjompa, M., Changula, K., Hang'ombe, B. 2022. "Pathogenicity of Bacteria Isolates Associated with Mortalities of Tilapia (*Oreochromis niloticus*) in Aquaculture Establishments on Lake Kariba, Zambia." Presentation, Feed the Future Innovation Lab for Fish Virtual Annual Meeting, Mississippi State University, U.S.A., August 2022.

Objective 3: Improve human outcomes from the aquaculture and fisheries sector

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.

Outcomes:

1. Information on new technologies, practices, and innovations in Bangladesh aquaculture value chains will be received by government, development partners, and researchers.
2. Bottlenecks in adoption and scaling of innovative technologies and practices will be reduced.
3. Institutional capacity will be increased to independently generate accurate spatialized information on aquaculture area, production, women and youth participation, and contributions to the economy in Bangladesh and beyond.

Achievements: During this reporting period and final year of the activity, the team achieved seven key accomplishments. The team successfully completed training on remote sensing methodologies for fishpond identification. The training was conducted through an online course of six 45-minute online tutorials and four live question and answer sessions for 91 registered participants from Bangladesh and 45 registered international participants. The team produced and disseminated thirteen short extension videos on innovative practices in the aquaculture value chain in Southwest Bangladesh. Two papers on fishpond detection methods developed by the project were published in the journals Remote Sensing and Environmental Modeling and Software. The team completed the Initial descriptive analysis of farm, trader, and input supplier survey datasets and drafted a paper on the results. Three abstracts were submitted and accepted to the World Aquaculture Society 2022 conference (to be held in Singapore in December). The team developed interactive webpages to display farm survey results and published them through the Southwest Bangladesh Aquaculture Data Portal. Finally, three project outreach workshops were completed in Dhaka, Gopalganj, and Khulna, which included a total 146 participants and received extensive national and local media coverage.

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 project through social media.

The final project closing workshop received strong buy-in from the Department of Fisheries (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.

Presentations and publications:

Ali, Hazrat, Belton, Ben, Murshed-e-Jahan, Khondker, Hernandez, Ricardo, Haque, Mohammad Mahfujul. 2022. “The Structure, Conduct, and Performance of the Midstream Segments of the Aquaculture Value Chain in Bangladesh.” Abstract, World Aquaculture Society Conference, Singapore, November 29-December 2, 2022.

Ferriby, Hannah, Amir Pouyan Nejadhashemi, Juan Sebastian Hernandez-Suarez, Nathan Moore, Josué Kpodo, Ian Kropp, Rasu Eeswaran, Ben Belton, Mohammad Mahfujul Haque. 2021.

"Harnessing Machine Learning Techniques for Mapping Aquaculture Waterbodies in Bangladesh." *Remote Sensing* 13, no. 23: 4890. https://doi.org/10.3390/rs13234890.

Haque, M. M., Belton, B., Ali, H., Hernandez, R. A., Khondker, M., Ferriby, H., Nejadhashemi, A. P. 2022. "Harnessing Machine Learning to Estimate Aquaculture's Contributions to the Economy of Southwest Bangladesh." Presentation, World Aquaculture Society, Singapore, November 2022.

Haque, M. M., Belton, B., Ferriby, H., Nejadhashemi, A. P., Moore, N., Hernandez-Suarez, S. 2022. "Performance of Sentinel-1 and 2 Imagery in Detecting Aquaculture Waterbodies in Bangladesh." *Environmental Modelling and Software*157, no. 105534 (November). doi:https://doi.org/10.1016/j.envsoft.2022.105534.

Ignowski, L. 2022. "Productivity of Micronutrients from Integrated Aquaculture-Agriculture Systems: Evidence from Bangladesh." Presentation, World Aquaculture Society, Singapore, November 2022.

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, Mississippi State University
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.

Outcomes:

1. Two MS students will be trained in research design, implementation, data analysis and interpretation, and manuscript writing.
2. One PhD student will be trained in development and implementation of a low-literacy tool to teach about the benefits of fish in the diet.
3. Two datasets about fish contaminant levels and the cost per nutrient of processed fish products will be gathered from fish markets in Delta State.
4. Three scientific articles will be published in peer reviewed journals: 1) Cost per nutrient of processed fish products in comparison to other animal source foods in Nigeria, 2) Food safety concerns of processed fish products in Nigeria, and 3) Development and testing of a low literacy tool to promote fish consumption.
5. Women and youth fish processing cooperative members will be trained in the benefits of fish for human consumption, how to use low-literacy tools, fish handling and processing techniques, and business and marketing skills.

Achievements: During this reporting period, the activity team implemented a post-education survey to 1) capture changes in knowledge, attitudes, and practices about nutrition and food safety concepts presented to women and youth fish processors during the first phase of the project's training program and 2) evaluate participants' use of the low-literacy tools developed and distributed to fish processors. In total, the team surveyed 92 fish processors (73% women). Most participants reported having knowledge of the health and nutrition benefits of consuming fish (90%), problems associated with smoked fish (65%), and sundried fish consumption (57%). Most reported positive

use of the low-literacy tools; 69% reported that they always used the tools, 78% reported the tools were comfortable to use, 69% reported that they were very attractive, 70% perceived the tools as very useful, 74% reported that the tools often served as reminders on the fish nutrition and food safety training, and 70% agreed that the tools were a conversation-starter on benefits of fish consumption and food safety.

The University of Calabar (UoC) MS students continued progress on their research proposals. The team completed collection of fish samples and pre-preparation of the samples to send for analyses, as well as multiple market surveys to collect data for the cost-per-nutrient guide with the final market survey completed in August 2022. The MSU PhD candidate successfully defended her dissertation in March 2022, and one dissertation paper was submitted for publication.

The project team, led by the UoC PI and Project Coordinator, initiated planning arrangements to complete the training program of fish processors in October 2022. The workshop will focus on fish processing techniques and business development skills.

Lessons learned: The primary challenge was the inability of UoC to access funds and reactivate their DUNS number, which resulted in a delay of project activities. The UoC PI consistently engaged with university administrative staff to resolve this issue, and communication has been maintained across the project team to provide support. 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) will be combined into one longer workshop covering all topics while maintaining the participant number.

Presentations and publications:

Adegoye G.A., Tolar-Peterson T., Pincus L. 2021. “Nutrition Education, Food Safety, and Safe Fish Handling and Practice Guide.” Feed the Future Innovation Lab for Fish activity, Nourishing Nations: Improving the Quality and Safety of Processed Fish Products in Nigeria.

Ene-Obong, H. N., Adegoye, G. A., Pasqualino, M., Tolar-Peterson, T., & Nuntah, J. 2022. “Improving Nutritional and Food Safety Knowledge of Small-Scale Fish Processors in Delta State, Nigeria.” Presentation, Role of Fish and Other Aquatic Animal-Source Food in Enhancing Nutrition and Food Security among Vulnerable Populations in Sub-Sahar Conference, American Public Health Association APHA Annual Conference, Boston, Massachusetts, U.S.A., November 9, 2022.

Silva, J., Adegoye, G. A., Tolar-Peterson, T., Evans, M. W., & Cheng, W. 2022. “Improving Nutrition and Food Safety Knowledge of Small-Scale Fish Processors in Delta State, Nigeria.” Presentation, Mississippi State University, March 22, 2022.

Silva, J., Pincus, L., Ene-Obong, H. N., Adegoye, G. A., Pasqualino, M. “Development and Validation of Nutrition and Food Safety Educational Material for Fish Processors in Nigeria.” Global Health Actions.

Silva, J., Pincus, L., Ene-Obong, H. N., Adegoye, G. A., Pasqualino, M. “Implementing Newly Designed Food Safety and Nutrition Training for Fish Processors in Nigeria.” JNEB.

Tolar-Peterson, T. Adegoye, G. A. 2022. T”eaching Nutrition and Food Safety to Fish Processors in Nigeria.” Presentation, Mississippi Academy of Nutrition and Dietetics Annual Conference, Bay St. Louis, Mississippi, March 2022.

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: Pamela Marinda, PhD, University of Zambia
HC PI; Netsayi Mudege, PhD, WorldFish

Objectives: FishFirst! Zambia aims 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 two years). The objectives of FishFirst! Zambia are 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.

Outcomes: To meet Objectives 1-3, FishFirst! Zambia outputs include 1) an assessment of existing fisheries enterprises disaggregated by key actors' gender and age to assess existing barriers and bridges to women- and youth-led fisheries development and pinpoint leverage points for growing this sector and 2) a fish-flow study of actors' engagement across the fish value chain (i.e., as producers, processors, marketers, and consumers). To meet Objective 4, FishFirst! Zambia outputs include a multi-stakeholder workshop to explore potential of upgrading the small-fish value chain via improving processing, storage, and trading methods to reduce postharvest losses and improve food safety. To meet Objectives 5-6, FishFirst! Zambia outputs include 1) development and testing of nutrient enhanced ComFA+Fish products/recipes for enhanced nutrition particularly benefiting women of reproductive age and children under two years in vulnerable households, and 2) exploration of options to scale the production and dissemination of the ComFA+Fish products/recipes with private and public sector actors, particularly women and youth entrepreneurs. FishFirst! Zambia contributes to Feed the Future objectives to understand why many Zambians, particularly women of reproductive age and children under two years, continue to lack dietary diversity and remain vulnerable to food insecurity and malnutrition.

Achievements: In FY22, the team engaged in a total of 67 activities. The team developed and vetted a "Consultant (Senior Human Nutrition Scientist)" advertisement to solicit Expressions of Interest (EOIs) from potential candidates and selected one PhD-level and one MSc level international human nutrition expert to consult with the FishFirst! Zambia team on development of the content for the nutrition trainings/cooking demonstrations and Sensory Panel I-II. The team finalized and submitted nine FishFirst! Zambia Phase II protocol documents to the Institutional Review Board, and MSU PIs attended the Full Board Review meeting at MSU. The team developed the sampling protocol and nutrient analysis protocol for the dried fish powder collected in Zambia and shipped to the U.S. for analysis. The team collected locally sourced Kapenta dried fish in Zambia, roasted it to remove any "fishy" taste/smell, commercially ground it into a fine powder, and packaged it for shipping. The team selected Mississippi State Chemical Lab in Starkville, MS, and the Mérieux NutriSciences Lab in Chicago, IL, to conduct different parts of the analysis and sent protocols to each.

The team collected information from the Zambian Department of Fisheries on population size and logistics of the Lake Kariba districts and villages to aid in participant selection for the nutrition trainings/cooking demonstrations and Sensory Panel I-II. The team developed and implemented the "Multi Stakeholder Analysis Protocol: Staple Foods Seasonality and Utilization in the Lake Kariba Region" with the MS student taking the lead. The team implemented training in Lake Kariba and

included 42 mothers and their 42 infants and young children (IYC). The team developed and implemented training modules for three nutrition trainings in June 2022. This included: 1) "FishFirst! Zambia – Nutrition for Healthy Women and Children in the First 1,000 Days of Life (Nutrition Training 1)" designed to encourage eating fish in first 1,000 days of life by providing mothers with knowledge of how to improve child nutrition, health, and household diet, 2) "FishFirst! Zambia – ComFA+Fish Cooking & Nutrition Demonstration 1 (Nutrition Training 2)" designed to encourage eating fish in first 1,000 days of life to improve nutritional outcomes for IYC vulnerable to stunting and chronic micronutrient deficiencies, and 3) FishFirst! Zambia – ComFA+Fish Cooking & Nutrition Demonstration 2 (Nutrition Training 3) designed to provide mothers with knowledge of how to improve child nutrition, health, and household diet.

The team conducted Sensory Panel I (Mothers' ComFA+Fish Taste-Test) and Sensory Panel II (Infants' & Young Children's Taste-Test of ComFA+Fish Complementary Porridge). These included women ages 18-49 years who were mothers of infants and young children ages 6-23 months. For the Sensory Panel I, the mothers were asked to separately taste and evaluate four ComFA+Fish traditional dishes. Using the "FishFirst! Zambia: Sensory Panel I Scoring Sheet/Evaluation Form (Mothers' Taste-Tests)" that was previously developed, the mothers scored each food on a 5-point hedonic scale. For the Sensory Panel II, the mothers were each asked to feed their child the ComFA+Fish Complementary Porridge at three separate time intervals. Using the "FishFirst! Zambia: Sensory Panel II Scoring Sheet/Evaluation Form (Infants' Taste-Tests)," mothers were asked to evaluate whether their child had positive or negative reactions to the ComFA+Fish Complementary Porridge. The team cleaned, coded, and conducted analysis on the results of the Sensory Panel I and II.

Lessons learned: Collaboration between the U.S.-based and Zambia-based team members through regularly scheduled online meetings continue to be highly productive. The FishFirst! Zambia team realized the need for an internationally recognized human nutrition expert (i.e., recognized as a leader in the field) and a Zambia-based human nutrition consultant to contribute to/provide feedback on all aspects of developing and testing the Complementary Food for Africa+Dried Fish Powder (ComFA+Fish) product/recipe prototype. One Masters-level and one PhD-level in-country human nutrition consultant were selected to assist the FishFirst! Zambia team with in-country implementation of the nutrition trainings/cooking demonstrations and Sensory Panel I-II.

Presentations and publications:

Chisopo, A., Marinda, P., Mudege, N., Read-Wahidi, M., Ragsdale, K., Kolbila, R., Smith, M. 2022. "Post-Harvest Fish Loss and Impacts on Small-scale Fishery Livelihoods in Zambia and Adjacent Countries: A FishFirst! Zambia Literature Review." Poster Presentation, 2022 Spring Undergraduate Research Symposium, Mississippi State University, Mississippi, April 13, 2022.

Iannotti, L. 2022. "Confronting Hidden Hunger: How Fish Can Help Fill Health Gaps Around the World." Presentation, Mississippi State University, February 9, 2022. https://www.fishinnovationlab.msstate.edu/events/2022/02/confronting-hidden-hunger-how-fish-can-fill-health-gaps-around-world.

Issac, A., Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaire, L., Kolbila, R., Funduluka, P., Muzungaile, T. 2022. "FishFirst! Zambia Phase II: Conducting Nutrition Trainings and ComFA+ Taste-Tests Among Mother-Infant Pairs at Lake Kariba." Poster Presentation, 2022 Summer Undergraduate Research Symposium, Mississippi State University, Mississippi, August 2, 2022.

Kolbila, R., Muzungaile, T., Issac, A., Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaire, L., Funduluka, P. 2022. "Preliminary Results for Mothers' ComFA+ Taste-Tests at Lake Kariba: FishFirst! Zambia Phase II." Poster Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, Virtual, August 8-10, 2022.

Malama, F., Marinda, P., Mudege, N., Read-Wahidi, M., Ragsdale, K., Kolbila, R., 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, Mississippi, April 13, 2022.

Ragsdale, K. 2022. “Quick Guide to Giving Great Scientific Presentations.” Feed the Future Innovation Lab for Fish Student Network Event, Webinar, April 13, 2022. https://rhody.webex.com/rhody/ldr.php?RCID=b58c4762f0f30de2f1dc6a76159aa81c.

Ragsdale, K., Castellanos, P., Sumner, D., O’Brien, C., Read-Wahidi, M., Garner, E., Rhoads, J. 2021. “Gender Across USAID’s Feed the Future Innovation Labs: Lessons and Approaches That Cultivate Gender-Transformative Agricultural Development (Panel Session).” Presentation, Cultivating Equality Conference 2021: Advancing Gender Research in Agriculture and Food Systems, CGIAR Gender Platform, Wageningen University & Research, Virtual, October 12, 2021. https://youtu.be/8HzFxYM320I.

Ragsdale, K., Iannotti, L. “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.” Presentation, 150th American Public Health Association (APHA) Annual Meeting, Boston, Massachusetts, November 6-9, 2022.

Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaire, L., Funduluka, P. 2022. “FishFirst! Zambia: Sensory Trials Results for ComFA+ Fortified Foods at Lake Kariba.” Presentation, 2022 Feed the Future Innovation Lab Directors Meeting, Virtual, September 21, 2022. https://mstate-my.sharepoint.com/:v:/g/personal/esc88_msstate_edu/EeA3UXbf57pOu0iBXpTyGBEBmWQ5R5tUlxe6ih53y_WKTw?e=pgRuUz.

Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaire, L., Kolbila, R., Funduluka, P., Muzungaile, T. 2022. “FishFirst! Zambia: Lake Kariba ComFA+ Taste-Tests and Nutrition Trainings.” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, Virtual, August 8-10, 2022.

Ragsdale, K., Read-Wahidi, M., Mudege, N., Marinda, P., Kolbila, R. 2022. “FishFirst! Zambia: Research on Individual- and Household-Level Food Insecurity Among Vulnerable Communities at Lake Kariba.” Presentation, 150th American Public Health Association (APHA) Annual Meeting, Boston, Massachusetts, November 6-9, 2022.

Ragsdale, K., Read-Wahidi, M., Mudege, N., Marinda, P., Kolbila, R. 2022. “Focusing a Gender Lens on Household Food Security among Vulnerable Lake Kariba Fisher Families: Household Hunger Scale II Results.” Presentation, International Conference on Quality Control, Gender and Food Security, London, United Kingdom, June 27-28, 2022.

Ragsdale, K., Read-Wahidi, M. R., Marinda, P., Mudege, N., Kolbila, R. 2021. “Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches (FishFirst! Zambia - Roundtable Discussion).” Presentation, 2021 Borlaug International Dialogue Side Event, World Food Prize Foundation, Virtual, October 19, 2021. https://youtu.be/qwJ6bKD4pdQ.

Ragsdale, K., Read-Wahidi, M. R., Marinda, P., Pincus, L., Torell, E., 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.

Ragsdale, K., Read-Wahidi, M. R., Torell, E. 2022. “Post-Harvest Fish Loss Assessment for Small-Scale Fisheries (PHFLA): An Open-Access Customizable Tool.” Feed the Future Innovation Lab for Fish Website, Mississippi State University, 9 pp., January 2022. https://www.fishinnovationlab.msstate.edu/sites/www.fishinnovationlab.msstate.edu/files/inline-files/Ragsdale%20et%20al_PHFLA_Survey%20Tool_FINAL_2.pdf.

Read-Wahidi, M., Ragsdale, K. 2022. “Gender Responsive R4D: What’s In It For You?” Presentation, Feed the Future Innovation Lab for Fish 2022 Virtual Annual Meeting, Virtual, August 8-10, 2022.

Shangala, S., Funduluka, P., Ragsdale, K., Mudege, N., Read-Wahidi, M., Muzungaire, L. 2022. “UNICEF Video: What to Feed Your Young Child (Tonga Translation).” Presented at the Feed the Future Innovation Lab for Fish FishFirst! Zambia Nutrition Training, June 2022. https://drive.google.com/file/d/1l3ytu--O7kz3o1qZVFXJxk5Jz-VUwwjn/view.

Wamukota, A., Kamu, E., Iannotti, L., Ragsdale, K., Read-Wahidi, M. R., Oaks, B., Tolar-Peterson, T., Adegoye, G., Pincus, L. 2021. “Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches (Roundtable Discussion Pre-Event).” Presentation, 2021 Norman E. Borlaug International Dialogue Side Event, World Food Prize Foundation, Virtual, October 19, 2021. https://www.fishinnovationlab.msstate.edu/events/2021/09/using-fish-mitigate-malnutrition-research-test-innovative-sustainable-approaches.

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.

Outcomes:

1. The effectiveness of a bundled, integrated intervention on healthy nutrition, income growth, and sustainable fisheries in coastal communities of Kenya will be examined.
2. Model socioenvironmental program framework for adaptation and replication in other small-scale fisheries and aquaculture communities in Kenya and globally will be developed.
3. Longitudinal difference-in-difference analyses will be completed for nutrition parameters during the first 1,000 days of life: dietary diversity, fish food intake, stunting prevalence, and height-for-age Z-scores.
4. Other impacts will be monitored, specifically household wealth and expenditures, women’s decision making and empowerment, fisheries yield, fishable biomass, fish spawning potential ratio, and fisher income and earnings.

Achievements: The team continued implementing the social marketing activities throughout the 12-month intervention period that ended in May 2022. The project managed to conduct all the social marketing campaign activities within the project's time frame. Participants continued to give positive feedback on the change in their practices and adopting what Samaki Salama taught them. This has been a gradual process documented across the different visits. The mothers/caregivers continued to report that more fish was brought home for consumption and that fishermen bring other food sources to supplement their diets unlike prior to the project. The team was able to collect endline data despite the political tension surrounding the general elections. Data analysis is ongoing. Fisheries data collection on catches from fishermen in both the modified traps (with escape gaps) and unmodified traps (traditional) was completed in May. The teams completed the preliminary data analysis in August showing that the catch in the modified traps had statistically significantly greater fish biomass and fewer juveniles. In addition, fishermen are making more money from their catches in the modified traps.

Lessons learned: For the follow-up interventions, a few participants (ranging from 3-15 households out of 200) were lost at various points of the Samaki Salama social marketing campaigns. To help, the Community Health Volunteers were involved in the follow ups, which made reachability a bit

easier. This was also experienced during the endline survey where 8 out of 200 households were completely lost to follow up in the Interventions Arm 1 and Arm 2, and 10 households were lost to follow up for the control arm. Reasons varied and included: some households had relocated and couldn't be traced; in one household, the study child had died; a few others refused to participate even after several attempts to have dialogue; some had left their matrimonial homes due to family disputes; and two fishermen died.

Presentations and publications:

Humphries, A., Iannotti, L., Wamukota, A., Kamau-Mbuthia, E. 2021. “Securing Small-Scale Fisheries in Kenya for Healthy Nutrition and Ecosystems.” Presentation, Borlaug Dialogue, Virtual, October 2021.

Humphries, A., Iannotti, L., Wamukota, A., Kamau-Mbuthia, E., Lesorogol, C. 2022. “Fish and Complementary Feeding Practices for Young Children: Qualitative Research Findings From Coastal Kenya.” PLOS One, 17(3), March 2022. doi:https://doi.org/10.1371/journal.pone.0265310.

Humphries, A., Iannotti, L., Wamukota, A., Kamau-Mbuthia, E., Lesorogol, C. 2022. “Samaki Salama for Healthy Child Growth and Sustainable Fisheries in Coastal Kenya.” Presentation, 150th American Public Health Association Annual Meeting, Boston, Massachusetts, U.S.A., November 2022.

Humphries, A., Iannotti, L., Wamukota, A., Kamau-Mbuthia, E., Lesorogol, C. “Child Nutrition in Fishing Versus Non-Fishing Households of Coastal Kenya.” Maternal & Child Nutrition.

Humphries, A., Iannotti, L., Wamukota, A., Kamau-Mbuthia, E., Lesorogol, C. “Samaki Salama for Healthy Child Growth and Sustainable Fisheries in Coastal Kenya: Study Protocol.” BMC Implementation Science.

Humphries, A., Wamukota, A., Cheupe, C., Obata, C., Cheupe, J. 2022. “Traps Modified With Escape Gaps and Fisher Training Promote Sustainable Fishing and Fish Consumption.” Presentation, 12th Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium, Port Elizabeth, South Africa, October 2022.

Iannotti, L. 2022. “Confronting Hidden Hunger: How Fish Can Fill Health Gaps Around the World.” Presentation, Mississippi State University, Starkville, Mississippi, U.S.A., February 2022.

Iannotti, L., Blackmore, I. 2022. “Samaki Salama: A Case Study in Coastal Kenya (SDG 2 and 12).” Presentation, Summer Research Program Seminar, St. Louis, Missouri, U.S.A., June 2022.

Wamukota, A., Blackmore, I. 2022. “Generating Demand for Healthy Diets: Samaki Salama Case Study.” Presentation, Advancing Nutrition Learning, Arlington, Virginia, U.S.A., June 2022.

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, MS, 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 is to investigate the biology, ecology, and population of the invasive crayfish in the Kafue floodplains and Lake Kariba. The specific objectives are

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.

Outcomes:

1. Assess the population structure of the introduced invasive crayfish population through increased knowledge of the crayfish in target water bodies. Monthly length and weight measurement in different locations will help understand growth, reproduction, and distribution of the introduced invasive species throughout the connected waterways.
2. Assess effects of the natural aquatic environment on crayfish population distribution and abundance. Data on physical and chemical water parameters will allow analysis of their effects on these factors.
3. Determine current harvest volumes from fished and farmed crayfish by analyzing existing postharvest utilization.
4. Assess the likelihood of potential trans-watershed boundary spread of the invasive crayfish by survey of rate of crayfish spread into the adjacent Cuando/Chobe sub-basin of the Zambezi that has a boundary with the ecologically critical Okavango Delta watershed.
5. Updated crayfish distribution data assessment in Zambia following protocols established by Douthwaute et al. [African J. Aquatic Sci. (2018) 43:353-366)] determining rates of natural spread vs. likely human mediated intentional stocking.

Achievements: In FY22, the activity team conducted a stakeholder workshop held at UNZA with the Department of Fisheries, Department of Environment, and environmental non-governmental organizations (ENGOs) based in Zambia. The workshop helped the team to make contacts and built partnerships for the data-gathering phase of the project. The team completed the instruments for crayfish harvest and utilization survey, focus group discussion, and crayfish trapping. In addition, the team developed an online Qualtrics poll to assess presence/absence of crayfish in a particular area or region, knowledge about crayfish harvest practices, and patterns of post-harvest utilization of crayfish. The first two methods/tools were field tested in Siavonga in March, while the online poll was tested in July-August. An application was developed for the UNZA Institutional Review Board (IRB) for ethical clearance, which covers the survey, online poll, focus group discussions, and key informant interviews. Monthly crayfish trapping studies were conducted in the Kafue River and Lake Kariba sites.

Data collected during the year provides information to the Zambian Department of Fisheries and the Zambian Department of Environmental Protection to better understand the ecological and social impacts of the invasive species. For example, the livelihoods of fishers who traditionally focus on the capture of river herring by way of an artisanal net fishery are finding their nets fouled by crayfish, requiring many to shift their target fisheries species to the crayfish by using alternative gear (with added expenses). Ecological effects include changes in the lake and river bottom (benthic) ecology by way of crayfish burrows and alteration of some food webs.

Lessons learned: Due to the nature of this type of study that targets large numbers of fisheries in remote communities, transportation and logistics are great challenges. The activity team had to make changes in the logistics and activities based on careful consideration of such challenges.

Presentations and publications:

Eilitta, M. 2022. “Background and Objectives: USAID-FIL Zambia Crayfish Project.” Presentation, Assessment of the Invasive Crayfish in Zambia Workshop-USAID, Lusaka, Zambia, March 2022.

Mudenda, G. 2022. “Population Ecology of the Introduced Crayfish in the Kafue Floodplain and Lake Kariba: Zambia.” Presentation, Assessment of the Invasive Crayfish in Zambia Workshop-USAID, Lusaka, Zambia, March 2022.

Nambeye-Kaonga, E. 2022. “Distribution Assessment and Harvesting of Crayfish on Lake Kariba and Kafue Floodplain.” Presentation, Assessment of the Invasive Crayfish in Zambia Workshop-USAID, Lusaka, Zambia, March 2022.

Rice, M. A. 2021. “Intensive Fishing Effort and Market Controls as Management Tools for Invasive Aquatic Species: A Review.” *Asian Fisheries Science* 34, no. 4 (December 2021): 383-392. https://doi.org/10.33997/j.afs.2021.34.4.011.

Rice, M. A. 2022. “Intensive Fishing Effort as a Tool for Managing Invasive Aquatic Species.” Presentation, Assessment of the Invasive Crayfish in Zambia Workshop-USAID, Lusaka, Zambia, March 2022.

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 is 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 are as follows:

1. Analyze the food and nutritional security impacts of increased aquaculture production.
    a. Can inland aquaculture continue to contribute to food and nutritional security of poorer households, as measured by nutritional elasticities?
    b. How do poorest households’ expenditures on fish, as disaggregated by species and/or source of production, differ from richer households as measured by the income elasticity?
    c. How does the expenditure on fish compare to expenditure on other major food items across households of different income levels? How true and/or strong is status bias in fish consumption?
2. Evaluate constraints in the aquaculture input markets that influence domestic market access for aquaculture producers.
    a. Determine availability of trade credits to fish farmers.
    b. How does volatility in input prices (corn price, soybean price, etc.) influence prices of farmed fish?
    c. What are the impacts of COVID-19 on aquaculture business operations, particularly small and marginal farmers, and on market prices of major aquaculture species at different geographical markets?
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.

Outcomes: The activity will lead to a better understanding of aquaculture value-chain development and its impacts on

1. Food and nutritional security of vulnerable households.

2. Market access for small and marginal farmers.
3. Linkages with input markets.
4. Export market competitiveness of major aquaculture products by scale of operation.

At the end of the activity, a conference will be held for stakeholders, including policymakers, to discuss the research outcomes and their policy implications. This will facilitate development of action plans to make the aquaculture value chain more inclusive and accessible to vulnerable households. Dr. Shamsul Alam of the Planning Commission of Bangladesh has kindly agreed to be an adviser for the activity, and his participation will increase the relevance of activity outcomes to the promotion of inclusive aquaculture value chains.

Achievements: In FY22, the activity team completed time series data on input price, fish price, and imported ingredients of commercial feeds. The team conducted a survey of 820 farmers to assess the status of aquaculture value-chains. The team also completed Household Income Expenditures Survey (HIES) data collection and is preparing the data for analysis. The team trained fish farmers in Patuakhali district and hatchery owners in Jashore district on scientific and business management practices in fish farming.

Lessons learned: Nothing to report at this time.

Presentations and publications:

Dey, M., Hossain, M. E., Khan, M. A. “How Price and Non-Price Factors Influence the Market Price of Major Carp Fish: An Advanced Time Series Analysis.” *Journal of the World Aquaculture Society.*

Dey, M., Hossain, M. E., Rahman, M. T., Khan, M. A., Islam, M. S. 2022. “Shrimp Export Competitiveness and its Determinants: A Novel Dynamic ARDL Simulations Approach.” Presentation, 9th Biennial Conference of BFRF, Dhaka, Bangladesh, May 2022.

Dey, M., Hossain, M., Rahman, M. T., Khan, M. A. 2022. “COVID-19’s Effects and Adaptation Strategies in Fisheries and Aquaculture Sector: An Empirical Evidence From Bangladesh.” *Aquaculture* 562, no. 3 (September 14, 2022): 1-14. doi:https://doi.org/10.1016/j.aquaculture.2022.738822

Dey, M., Hossain, M., Rahman, M. T., Khan, M. A., Islam, M. 2022. “Shrimp Export Competitiveness and its Determinants: A Novel Dynamic ARDL Simulations Approach.” *Aquaculture Economics & Management,* (June 2022): 1-30. doi:https://doi.org/10.1080/13657305.2022.2089772.

Dey, M., Khan, M., Hossain, M. E., Rahman, M. T. 2022. “COVID-19’s Effects and Adaptation Strategies in Fisheries and Aquaculture Sector: An Empirical Evidence From Bangladesh.” Presentation, 17th Biennial Conference of BAEA, Dhaka, Bangladesh, September 2022.

Dey, M., Khan, M., Hossain, M. E., Rahman, M. T., Islam, M. S. 2022. “Shrimp Export Competitiveness and its Determinants: A Novel Dynamic ARDL Simulations Approach.” Presentation, 17th Biennial Conference of BAEA, Dhaka, Bangladesh, September 2022.

Dey, M., Khan, M., Rahman, M. T. 2022. “Are Trade Credits a Drain for Gain in the Aquaculture Industry of Bangladesh?” Presentation, 9th Biennial Conference of BFRF, Dhaka, Bangladesh, May 2022.

Dey, M., Khan, M., Rahman, M. T. 2022. “Are Trade Credits a Drain for Gain in the Aquaculture Industry of Bangladesh?” Presentation, 17th Biennial Conference of BAEA, Dhaka, Bangladesh, September 2022.

Dey, M., Khan, M., Rahman, M. T., Islam, I. “Are Trade Credits a Drain for Gain in the Aquaculture Industry of Bangladesh?” *Agricultural Finance Review*.

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: This research will

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.

Outcomes: This research will test the hypothesis that oysters are the primary food source for iron and zinc among women shellfishers in West Africa, using Ghana as a case study. It will also measure heavy metal contamination in oysters to evaluate health risks of oyster consumption. This research has the potential to identify oysters as a key contributor of iron and zinc in the diet of women shellfishers, reducing the risk of anemia and micronutrient deficiencies. Results from this study will inform relevant stakeholders whether oysters should be recommended to women of reproductive age to reduce anemia prevalence or avoided because of heavy metal contamination. If it is determined that oysters are providing a critical micronutrient contribution to the diet but are also contaminated with heavy metals, this research may be used as a call for action to address heavy metal contamination in the environment.

Specific outcomes of this work will include

1. A stronger evidence-base of the nutritional benefit of oysters for women of reproductive age will be provided.
2. Heavy metal contamination levels will be identified for oysters from the three study sites in Ghana.
3. Results will be provided to health authorities and other stakeholders in Ghana.
4. Findings will result in one or more publications in a peer-reviewed journal.
5. Findings will be integrated into the Women Shellfishers and Food Security project multivariate analysis research report and stakeholder toolkit for dissemination to women shellfishers, government, and academic stakeholders in coastal West Africa from Senegal to Nigeria.

Achievements: In FY22, the activity team obtained the study's ethics approval from the Ghana Health Service Ethics Review Committee. The team completed the statistical analysis of the women's nutrient intakes from the repeat 24-hour recalls, including intake of oysters, specific dietary nutrients, and contribution of oysters to total iron and zinc intakes. The team conducted analysis on the 915 oyster samples that were collected from the three sites (i.e., 305 samples per site) for 16 minerals, including 5 macrominerals (calcium, magnesium, phosphorus, potassium, and sodium), 8 trace minerals (chromium, cobalt, copper, iron, manganese, nickel, selenium, and zinc), and 3 heavy metals (cadmium, mercury, and lead). In addition, the team completed an analysis of the health risks of oyster consumption among the women shellfishers with respect to three heavy metals (cadmium, mercury, and lead). The Fish Innovation Lab provided additional funding in FY22 to conduct the selenium and arsenic analysis. The selenium analysis was completed.

Lessons learned: One challenge was getting each of the collected 915 oyster samples analyzed for 17 minerals because the analysis costs increased consistently over time. The team was able to get a good discount on the analysis from the University of Ghana ECO LAB (where the analysis was conducted) and, in addition, involved a graduate student in the analysis, so that the labor cost could be reduced.

Presentations and publications:

Oaks, B. 2021. "Micronutrient Impact of Oysters in the Diet of Women Shellfishers." Presentation, Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches, Borlaug Dialogue Side Event, Online, October 2021.

Oaks, B. 2021. "Oysters, Micronutrients, and Women's Nutrition: Current Challenges and Research in West Africa." December 2021.

Oaks, B., Adu-Afarwuah, S. 2021. "Assessment of Oyster Consumption, Anemia, and Food Insecurity." Presentation, Advancing Gender Research in Agriculture and Food Systems, Cultivating Equality Conference, Online, October 2021.

Oaks, B., Adu-Afarwuah, S. 2022. "The Women Shellfishers and Food Security Project: Nutrittion Element." Presentation, Stakeholder Engagement on West Africa Shellfish Regional Assessment Report and Toolkit, Virtual, March 2022.

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 its first buy-in award at the end of FY21. The $200,000 buy-in from the Bureau for Development, Democracy, and Innovation will support 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 DWF activity fits within the Fish Innovation Lab's theory of change and its three areas of inquiry. This research will:

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

Outcomes: The final deliverables of the DWF activity will be defined in the annual work plans but are expected to include communications materials related to transparency and sustainability in licensing and supply chains associated with DWF activity, a summary communications product comparing licensing in priority countries, a project report related to the socioeconomic impacts of DWF on national fisheries and fisherfolk, and mission level-briefs and presentations.

Achievements: On Objective 1, the team organized orientation meetings with USAID missions and stakeholders. Mission concurrence to implement the research activities in Peru, Madagascar, the Philippines, and the Pacific Islands was obtained, and fish stocks for research were selected in collaboration with USAID Missions. The team completed a literature review on existing research and data for each fish stock across all focal geographies. The team outlined the process for determining the extent to which DWF currently impacts fish availability, access, and potential utilization, and for estimating the optimal catch allocations to DWF to provide

resilience to future domestic catches. The team began analysis of data obtained from the University of British Columbia's Sea Around Us database. On Objective 2, the team outlined methods to be used for examining the characteristics and impact of existing DWF fishing access agreements within priority geographies. The team compiled and made an initial analysis of species-specific nutritional content data, national malnutrition statistics, caloric/nutrient intake statisticss, and related data that describes DWF landings in terms of food security (rather than just fishery production) for each focal geography. The team shared the framework on existing licensing agreements (or lack thereof) in the four priority geographies and received feedback. Results from research to date have led to a greater appreciation for the opportunity cost, both indirectly through reduced revenue and directly through reduced availability and access to fish, of DWF activities.

Lessons learned: Progress to date makes clear that research methods (particularly for Objective 1) and outputs (for both objectives) will look different across the four case study regions. For example, for Objective 1 a uniform approach for data analysis is not feasible because the same kind of data related to DWF catch size and composition is not available across all four regions. For Objective 2, the team learned through collaboration with the USAID mission almost no legal distant water fishing is occurring in the Philippines, requiring that for this case study we shift our focus on a DWF licensing system evaluation away from current conditions and towards considerations by the Philippines of future engagement with foreign fishing access arrangements and what best practice would look like in potential future scenarios.

Presentations and publications: None to report.

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. All Fish Innovation Lab-funded subawards include activities to strengthen local partner, student, extension, and broader stakeholder capacity. The strategy includes traditional classroom and online training, mentoring, partnering, and "learning by doing" models founded in collaborative research. Activities contributed to US-based and in-country teams researcher engagement enabling formation of an aquaculture and fisheries community of practice; long-term, hands-on, graduate training of students in country; and engagement of stakeholders, community members, and end-users through short-term trainings and direct involvement in research activities. Notable HICD accomplishments in FY22 include:

1. The ME capacity development specialist launched the Fish Innovation Lab student network. A total of 30 students participated in four virtual meetings led by senior researchers on the topics of presentation skills, surviving as a graduate student with advisors, leadership within a university setting, and mixed methods in data collection.
2. The ME gender and youth equity specialist and co-specialist led or participated in 18 activities designed to promote or contribute to capacity development. They produced five technical reports, organized and facilitated three trainings and workshops, organized and chaired two conference sessions, presented at one conference session, and seven times highlighted research on digital platforms and media outlets.
3. The Bangladesh **Machine Learning activity** invested heavily in capacity development during its final year. 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 thirteen 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 project outreach workshops for government, non-profit organizations, and the private

sector in Dhaka, Gopalganj, and Khulna, with 146 participants, receiving extensive national and local media coverage. These workshops received strong buy-in from the Department of Fisheries (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.

4. The Bangladesh **Cryogenic Sperm Banking activity** trained 225 stakeholders (more than 40% youth and approximately 30% female), including hatchery managers and operators, nursery operators, fish farmers, junior faculty members, three PhD, and four MS students in a series of nine workshops in the Mymensingh, Faridpur, Jashore, and Barishal regions of Bangladesh. The training covered sperm cryopreservation techniques, breeding of fish using cryopreserved sperm, and growth performance of cryopreserved sperm-originated seeds. The activity conducted breeding of six carp species using cryopreserved sperm in eight public and 14 private sector hatcheries in these regions producing seeds stocked in 17 hatcheries for brood production and in fish farms. Seeds from cryopreserved sperm had higher growth than seeds from sperm of hatchery-origin males. The seeds produced from those broods are expected to have higher growth and production. The activity's stakeholder engagement and capacity development across government, the 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.
5. The Bangladesh **Foodborne Pathogens activity** provided intensive training to the laboratory personnel from the fisheries and food safety laboratories operated by the government in Bangladesh last year. 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. In FY22 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. As a part of long-term capacity building initiatives, the project enrolled and provided two MS students technical training on analysis of fish and environmental samples for microbial contamination, data analysis, interpretation, scientific writing, and presentation of research findings. The students presented their findings at the Fish Innovation Lab annual meeting in June 2022.
6. The Nigeria **Improving Biosecurity activity** webinar session in June 2022 hosted in collaboration with the AAM contributed to awareness and capacity building of participants from Asia and Africa. A workshop in August 2022 on catfish and tilapia disease 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 University of Ibadan (UI) launched the E-Aqua health diagnostic extension platform for farm cluster leaders, resident veterinarians, and UI researchers. It enhances prompt response to disease outbreaks and supports fish farmers. A capacity gap of concern identified by the project is 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.
7. The Nigeria **Lean Production Systems activity** engaged 219 farms to improve farm efficiency by applying Lean management tools to identify and address 602 incidents of lost efficiency in the areas of fish mortality, labor and energy use, and feed cost, increasing farmer capacity to problem solve and increase profits.
8. The Nigeria **Aquaculture Diversification in Rural Communities activity** produced and packaged four new innovations for dissemination and identified locally available feedstuffs—

fish offal and rice bran. The activity's approach to the research facilitates farmers to sustain the increased productivity of their farms and learn additional management techniques through a participatory farmer field school on farm diversification platform for capacity development.

9. The Nigeria **Nourishing Nations activity** continued to strengthen capacity among women and youth fish processors in Delta State. Fish processors began organizing into business cooperatives. The activity contacted these groups to participate in the next phase of the training program to continue building their techniques in producing high quality, safe, and nutritious processed fish products for local consumption and improving their business skills in marketing improved products.
10. The **Samaki Salama activity** in Kenya conducted an assessment of its social marketing campaign to increase fish consumption and improve healthy behaviors. Mothers and caregivers reported improved practices in child feeding and care and that they were educating others. Fishermen reported increased revenue from catches in modified traps. Some fishermen reported making more modified traps, putting into practice their capacity to adopt the sustainable fishing practices learned based on market incentives.
11. The Kenya **Coral Reef Fishery Sustainability activity** mobile app enabled community data collectors 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. More community members learned how to use it in FY22. A comparison of trained fisheries and community members' collected data showed that communities are able to conduct successful monitoring. This finding resulted in a change of roles of fisheries officers from recording fish weights to recording fish length. The project also 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.
12. The Cambodia **Fisheries and Food Processing activity** organized a workshop with the participation of diverse stakeholders, including 14 fishers from the Koh Kong province, who are members of the project's Citizens Science Program, three fishers from the Pursat province, villagers (including the fishers' wives, sons, and daughters), the Cambodian Fisheries Authority, the US Forest Service, and Conservation International. Most of the participants were youths. Trained local fishers collected data using the Fisheries Harvest and Recovery Monitoring Protocol, and the Community Fisheries Assessment Tool: iFISH App, resulting in individual capacity development, buy-in for sustainable monitoring of fisheries, and empowerment of fisheries communities in the Sre Ambel River activity area. The activity submitted sensory panel results for publication detailing the fish species and cooking methods that were preferred by Cambodian consumers. These data provide the fish and foodservice industries in Cambodia with insights into products they should target to improve profitability and their livelihood. The sensory panels and surveys also provide a model for future studies.

Short-Term Trainings

FY22 results for EG.3-2.1 reflect 39 short-term trainings conducted by activities in FY22, reaching 2,211 beneficiaries. This includes 60% males and 40% females (1,316 males and 895 females). These results reflect activities led by research teams, and examples include training on Integrated Fish Farming - Benefits, Operational and Management Procedures; Machine Learning to Identify Aquaculture Waterbodies; caregivers cooking demonstrations on how to prepare nutritious meals and retain nutrients that are commonly lost while cooking; and fish farmers training on scientific and business management practices.

Table 2: Short-Term Trainings

Country	Activity	Number Trained			Brief Purpose of Training
		Male	Female	Total	
Nigeria	Halwart - Farm Diversification	337	123	**460**	Training of enumerators for socio economic and field surveys. Training of farmers on on-farm data collection and recording. Trainings of farmers on the proper sustainable methods of aquaculture in the rice-based farming system.
Nigeria	Chadag Biosecurity	14	6	**20**	Training of government stakeholders on bacterial DNA extraction and bacteriology.
Nigeria	Subasinghe - Lean Production Systems	331	120	**451**	Training on applying Lean management tools to identify waste streams and improve efficiency in production. Upgrade training on Lean data collection and REDCap.
Bangladesh	Belton - Machine Learning	106	30	**136**	Training of beneficiaries on machine learning to identify aquaculture waterbodies.
Bangladesh	Islam - Foodborne Pathogens	2	1	**3**	Follow-up training at Department of Fisheries lab on isolation and identification of pathogenic microbes from fish samples.
Bangladesh	Dey - Market Analysis	73	9	**82**	Training of data enumerators to gather high-quality primary data and meet the project's objectives. Fish farmers training on scientific and business management practices. Hatchery owners training on scientific and business management practices.
Kenya	Iannotti - Samaki Salama	214	233	**447**	Training of community health volunteers to conduct home visits. A series of ten fisher trainings focused on better understanding the challenges fishers face providing for their families, the opportunities provided by using the modified traps, knowledge of child nutrition, and the importance of bringing some of their catch home to their families.
Cambodia	Correa - Cambodian Fisheries & Food Processing	104	103	**207**	Training on data visualization iFISH App to summarize current harvest trends for the Stre Ambel River fisheries. Training to help identify current processing and preservation techniques and nutrition knowledge of Cambodian fishermen.
Cambodia	Hok - Bighead Catfish	9	2	**11**	Training on the installation of materials to operationalize an existing wet laboratory for aquaculture feed nutrition research. Training of the RUA personnel on the operation of a wet lab.
Kenya	McClanahan - Coral Reef Fishery	55	8	**63**	Community fish biomass training to create awareness among the community project beneficiaries on the current fisheries status in their areas and enhance their knowledge and skills on how to conduct a stock assessment. Length-Weight monitoring training on WCS fish landing length and weight data collection protocols.

Zambia	Ragsdale - FishFirst! Zambia	46	240	**286**	Training to provide mothers with knowledge of how to improve child nutrition, health, and household diet through: 1) learning about Complementary Food for Africa+Dried Fish Powder (ComFA+) and how its key ingredient is locally sourced small pelagic fish such as Kapenta or Chisense that are dried, roasted to remove any fishy taste, and ground into a fine powder, 2) learning about how this dried fish powder can then be easily mixed with other nutritious ingredients that are also locally sourced – such as groundnut powder, orange-fleshed sweet potato, soybean powder, pumpkin leaves, etc., to improve nutritional benefits of complementary foods for IYC.
Ghana	Oaks - Oyster Nutrition	25	20	**45**	Workshop training to disseminate findings on key linkages in the Theory of Change based on the site-based research multivariate analysis.

Long-Term Trainings

During the FY22 period, the Fish Innovation Lab had 42 individuals/students (24 males and 18 females) enrolled in or who had graduated from a bachelor's, master's, or PhD program receiving long-term training, mentorship, or apprenticeship in Fish Innovation Lab aquaculture, fisheries, resilience, and food-system activities. In the fiscal year, 10 individuals completed training; 21 individuals were continuing training to the next fiscal year; and 11 new individuals were added. This includes five from the Cryogenic Sperm Banking activity, two from the Foodborne Pathogens activity, three from the Vaccines for Tilapia activity, and one from the Oyster Nutrition activity.

Table 3: Long-Term Trainings

PI and student number	Sex	Home Institution Name	Degree	Major	Program End Date	Degree Granted	Student's Home Country	Status FY22
Belton	M	Bangladesh Agricultural University	PhD	Aquaculture Systems and Development	2022/23	No	Bangladesh	Continuing
Chadag 1	M	University of Ibadan	Master, Veterin-ary Public Health (MVPH)	Fish Epidemiology	2022/23	Yes	Nigeria	Continuing
Chadag 2	F	University of Ibadan	MVPH	Fish Epidemiology	2022/23	Yes	Nigeria	Continuing
Correa 1	M	Royal University of Phnom Penh	Master of Science (MS)	Biodiversity	2023	Yes	Cambodia	Continuing
Correa 2	F	Royal University of	MS	Food Science & Technology	2023	Yes	Cambodia	Continuing

		Phnom Penh						
Halwart 1	M	University of Ibadan	PhD	Agriculture Economics	2023	No	Nigeria	Continuing
Halwart 2	F	University of Ibadan	PhD	Fisheries Management	2023	No	Nigeria	Continuing
Halwart 3	M	Usmanu Danfodiyo University, Sokoto	MS	Fisheries Ecology	2021	No	Nigeria	Continuing
Halwart 4	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Continuing
Halwart 5	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Continuing
Halwart 6	F	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Continuing
Halwart 7	M	Federal University of Technology Owerri	MS	Fish Nutrition	2021	No	Nigeria	Continuing
Halwart 8	M	University of Ibadan	MS	Fish Nutrition	2022	No	Nigeria	Continuing
Hok 1	M	Royal University of Agriculture	PhD	Agricultural Science	TBD	No	Cambodia	Continuing
Iannotti 1	M	Pwani University	NA – postdoc	NA – postdoc	NA – postdoc	NA – postdoc	Kenya	Complete
Iannotti 2	F	University of Rhode Island	PhD	Environment and Life Sciences	TBD	No	USA	Complete
Iannotti 3	F	Washington University in St Louis	NA – postdoc	NA – postdoc	NA – postdoc	NA – postdoc	USA	Complete
Iannotti 4	F	Washington University in St Louis	Master of Public Health (MPH)	Global Health	Aug-19	Yes	USA	Complete
McClanahan 1	F	University of Rhode Island	PhD	Biological and Environmental Sciences	Jul-05	No	USA	Continuing
Pasqualino 1	F	Mississippi State University	PhD	Food Science, Nutrition and Health Promotion – concentration Nutrition	2021	Yes	Nigeria	Complete
Pasqualino 2	F	University of Calabar	MS	Nutrition & Food Science	2022/23	No	Nigeria	Continuing
Pasqualino 3	M	University of Calabar	MS	Nutrition & Food Science	2021/22	No	Nigeria	Continuing
Ragsdale 1	M	University of Zambia	MS	Agricultural Economics	TBD	No	Zambia	Complete
Ragsdale 2	F	University of Zambia	MS	Human Nutrition	TBD	No	Zambia	Complete
Sarder 1	M	Bangladesh Agricultural University	PhD	Fish Breeding and Biotechnology	2024	No	Bangladesh	Continuing

Sarder 2	M	Bangladesh Agricultural University	MS	Fish Breeding and Biotechnology	2021	No	Bangladesh	Continuing
Sarder 3	M	Bangladesh Agricultural University	MS	Fish Breeding and Biotechnology	2021	Yes	Bangladesh	Complete
Sarder 4	M	Bangladesh Agricultural University	PhD	Fish Breeding and Biotechnology	2024	No	Bangladesh	Continuing
Sarder 5	M	Bangladesh Agricultural University	MS	Fish Breeding and Biotechnology	2022	Yes	Bangladesh	Complete
Sarder 6	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	New
Sarder 8	M	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	New
Sarder 9	M	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	New
Sarder 10	F	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	New
Sarder 11	F	Bangladesh Agricultural University	MS	Fisheries Biology and Genetics	2023	No	Bangladesh	New
Islam 1	M	University of Dhaka	MS	Fisheries and Bio-technology	2022/23	No	Bangladesh	New
Islam 2	F	University of Dhaka	MS	Fisheries and Bio-technology	2022/23	No	Bangladesh	New
Rice 1	F	University of Zambia	MS	Research Training	2022	No	Zambia	Continuing
Hangombe 1	F	University of Zambia	PhD	Research Training	2024	No	Zambia	New
Hangombe 2	M	University of Zambia	MS	Research Training	2023	No	Zambia	New
Hangombe 3	M	University of Zambia	MS	Research Training	2023	No	Zambia	New
Oaks 1	M	University of Ghana	PhD	Research Training	2024	No	Ghana	New

Implementation of Other Cross-Cutting Themes

The Fish Innovation Lab has 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 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. FY22 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 is led by experts Kathleen Ragsdale and Mary Read-Wahidi. They support subaward activities by providing overall guidance and individualized support. They promoted the importance of gender-transformative and youth-inclusive agricultural development through 25 gender/youth-related activities, with a focus on high-impact and open-access resources as well as collaborations across cross-cutting themes and across Innovation Labs. Key examples include:

1. Developing the online course, "Your Comprehensive Guide to Conducting Focus Groups in Village Settings for Gender Responsive Agricultural Development," which is jointly sponsored by the Feed the Future Innovation Lab for Fish, Feed the Future Soybean Innovation Lab, and the Gender Impacts Lab.
2. 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.
3. Jointly organizing the "Integrating Gender throughout the Project Life Cycle of Innovation Lab," USAID Feed the Future Innovation Lab Community of Practice: Virtual Workshop.
4. Facilitating a visit to Mississippi State University by Dr. Lora Iannotti, Fish Innovation Lab nutrition specialist. Dr. Iannotti presented, "Confronting Hidden Hunger: How Fish Can Help Fill Health Gaps Around the World."
5. Jointly organizing, with Dr. Iannotti, the American Public Health Association (APHA) session, "Role of Fish in Mitigating Food Security and Nutrition Gaps among Vulnerable Populations in Developing Countries: Evidence Across Sub-Saharan Africa," which features results from Fish Innovation Lab-funded projects.

The gender and youth equity specialists contributed to several communications and outreach initiatives. These included blog posts for Agrilinks and the Fish Innovation Lab website:

- 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: Gender and youth Engagement, Human Nutrition and Food Security).
- "MSU Feed the Future Projects Gain Global Attention at Borlaug International Dialogue." *Starkville Daily News*, November 6, 2021. https://www.pressreader.com/usa/starkville-daily-news/20211106/page/2/textview. (Cross-Cutting: Gender and youth Engagement, Human Nutrition and Food Security).
- 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: Gender and youth Engagement, Human Nutrition and Food Security, Capacity Development)
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- 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: Gender and youth Engagement, Capacity Development).

In FY22, Ragsdale and Read-Wahidi also prepared to administer Wave II of the GRADA-FIL, a major activity of the Gender and Youth Engagement ME, intended for the final year of Fish Innovation Lab funded three-year projects. They made the following progress:

- Coordinated with Fish Innovation Lab ME to set a plan and timeline for GRADA-FIL Wave II roll-out between October 20, 2022, and December 1, 2022.
- Promoted the upcoming GRADA-FIL Wave II among project PIs at the Fish Innovation Lab Annual Meeting in August 2022.
- Developed and distributed email correspondence with project PIs to seek contact information of additional team members for the GRADA-FIL Wave II mailing list.
- Developed communications for the email invitation to complete the GRADA-FIL Wave II.

Gender and youth results associated with the Fish Innovation Lab research activities include:

- The **FishFirst! Zambia activity** conducted nutrition trainings for mothers of reproductive age (18-49 years) with infants ages 6-23 months and sensory panels to determine acceptability of the ComFA+Fish product/recipe prototype. The trainings included: Nutrition for Healthy Women and Children in the First 1,000 Days of Life (Nutrition Training 1) for 66 participants, 79% female and 58% youth (age 15-29 years); ComFA+Fish Cooking & Nutrition Demonstration 1 (Nutrition Training 2) for 66 participants, 79% female and 58% youth; ComFA+Fish Cooking & Nutrition Demonstration 2 (Nutrition Training 3) for 77 participants, 88% female and 64% youth.
- The **Aquaculture Diversification in Rural Communities activity** in Nigeria directed interventions toward robust youth engagement in the aquaculture value chain and tailored them to ensure youth access to knowledge, information, and education related to productive land use, extension services, and mentorship. As a result, rice-fish farming capacity enhancement activities had 82% youth participation.
- The Nigeria **Farming Insects** team continues to prioritize all interested women in its approach to the selection of participants in Nigeria for research, training, and support for fish farming with BSF larvae feeds because there are few women fish farmers. The team will also prioritize women for development of BSF larvae production for sale to feed mills, an activity that could potentially involve more women producers.
- The Nigeria **Nourishing Nations activity** conducted a post-training survey, showing that women and youth fish processors reported frequent use of the low literacy tools, including wristbands and fans developed by the project. In addition to serving as a means to spread information and increase knowledge about the benefits of fish for human nutrition, the tools helped fish processors better market their fish products, strengthening their engagement with consumers, business skill development, and overall productivity of their economic activities in the fish value chain. These tools increased knowledge among women fish processors about proper nutrition and empowered their decision-making ability on business practices.
- 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 males were youth. The team prioritized and included almost 50% youth vendors in its study of behavioral practices like fish transportation, storage, and quality of water used in fish storage because they have more opportunities to learn and adopt future interventions and were more enthusiastic about participating in the interviews. During the activity’s short-term training

period, the team trained one female microbiologist from the government fisheries lab who has been playing a key role in testing fish samples for different microbiological parameters for regulatory purposes.

- The Cambodia **Fisheries and Food Processing activity** selected one woman to participate in data collection in the Citizen Science Fisheries Harvest program. One female research assistant works with the graduate student and the local project coordinator compiling data from fishers, digitizing data, and conducting quality assurance and quality control. These activities contribute to equalizing training opportunities, participation in decision making, and future employment. A female graduate student and her female coworker with the Wildlife Conservation Society submitted a travel request to come to the U.S. to complete sample processing. For the activity's surveys, 56 males and 44 females completed the survey, and 55 females and 45 males participated in sensory panels.
- The Kenya **Samaki Salama activity** targeted both fathers and mothers of young children 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 Kenya **Coral Reef Fishery Sustainability activity** trained seven females out of a total of 18 participants, 10 of whom were youth, in a recent fish weight-length training, as they worked to address challenges, including women without swimming skills in community-based fisheries monitoring. The participation of women and youth facilitate equity and transfer of experiences by skilled older persons to empower youth and willing women. Active collaboration with government institutions such as the Fisheries Department, the Kenya Marine and Fisheries Research Institute, and NGOs also empowers women as these organizations are vocal on women's rights and provide opportunities to women who then become exemplary to communities. Although opportunities presented to communities are competitive (such as fish landing monitoring), women emerge among the best candidates and are hired.

Human Nutrition

Nutrition is an essential theme within the Fish Innovation Lab as both a cross-cutting issue and part of the human outcomes Area of Inquiry. One particular emphasis is 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 targets 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. Dr. Lora Iannotti at WUSTL provides expertise and leadership for the nutrition theme in the Fish Innovation Lab. In FY22, Iannotti and her colleague Elizabeth Hahn supported the ME by assisting PIs and other team members to better characterize nutritional problems and fine-tune the targeting and intervention strategies for reaching vulnerable groups. Iannotti met with the PIs of FishFirst! Zambia, Lean Productions Systems, Biosecurity, and Nourishing Nations in Nigeria, and Cambodian Fisheries and Food Processing to enhance nutrition programming in these activities. In February, Iannotti traveled to MSU to meet the ME and project PIs in-person. She also presented a seminar to MSU faculty and students, which was titled, "Confronting Hidden Hunger: How Fish Can Fill Health Gaps Around the World."

The ME gender and youth equity specialists also contributed to this cross-cutting theme, leading or participating in nine activities that promote human nutrition and food security (three for research highlighted on media outlets, two technical reports, two trainings/workshops, and four conference sessions).

The Fish Innovation Lab is developing an online course on fish and nutrition. Meetings were held with Glenn Ricci, Fish Innovation Lab capacity development specialist. Iannotti and her colleague Vanessa Chen are developing the learning objectives, modules, and case studies.

In addition to her contributions to publications and communications already indicated in the capacity development and gender and youth cross-cutting theme sections above and the Research Strategy section, Iannotti published a manuscript in December 2021 Food and Nutrition Bulletin 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.

Working with two members of her E3 Nutrition Lab and Dr. Brietta Oaks, Dr. Iannotti designed and advanced progress on a systematic review to examine the evidence-base for the effects of mollusks and crustaceans on maternal and young child nutrition and health outcomes. They will draft and submit a manuscript in FY23.

Activity-specific nutrition results include:

- The Nigeria **Aquaculture Diversification in Rural Communities activity** recognizes that the contribution of fish to household food and nutrition security depends upon availability, access, and cultural and personal preferences. The activity explores 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. 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. Mothers/caregivers reported increased fish consumption after the activity's nutrition education session. 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.
- The Cambodia **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 cook fish by boiling in water. This is consistent with many residents believing broth is the most nutritious option. When cooking fish for their family, 72% said they cook 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 provide an idea of what is common for Cambodian fishermen for preservation, processing, and household cooking of fish and what consumers believe about where the nutrition values come from. This, in combination with the nutritional database, will allow the activity to communicate to

Cambodians on methods of fish processing, preservation, and cooking to provide the most nutrition, best quality, and flavor of their fish products during future workshops.

- The Kenya **Coral Reef Fishery Sustainability activity** established the status of stocks through the monitoring systems put in place. The current status shows there is a need for management measures to ensure sufficient fish to feed families since the available fish are sold to meet the economic needs of communities. Management efforts by communities and government are ongoing. In addition, a pre socioeconomic survey analysis is being conducted to help generate more information on rates of consumption in each of the project sites.
- **Nourishing Nations** 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 are designed to improve the quality of fish products rather than access. Key results are detailed under the gender crosscutting theme.
- The Ghana **Micronutrient Impact of Oysters activity** research focused on women shellfishers at three estuary sites in Ghana, including evaluating the extent to which oysters contribute to the micronutrient intakes of the women, as well as the potential health risks the women face without their knowledge as a result of heavy metal contamination of oysters. So far, women shellfishers in Ghana have received little research attention. Therefore, research recommendations will be available to local authorities and help influence the health and nutrition of women shellfishers at the three estuary sites and similar settings.

Resilience of Value Chains/Households

Improving resilience in aquaculture and fisheries relies upon strengthening adaptive capacity and reducing the risks of recurrent crises, shocks, and stresses. Joanna Springer from RTI International provides expertise in resilience for the Fish Innovation Lab and the ME Partners. She launched the online resilience training developed in FY21 and reached out to several project teams for follow up consultations. She identified four subaward activities that address resilience at the systems level. Ecologically, resilience is addressed for fisheries in Cambodia and Kenya, and in terms of biosecurity, resilience is an activity theme for aquaculture systems in Nigeria and Bangladesh. Springer had in-depth discussions with the Nigeria Biosecurity team and adapted the framework of resilience capacities to incorporate biosecurity and antimicrobial resistance response. She developed a graphic mapping of seven Fish Innovation Lab projects to USAID's resilience framework to highlight activities with a strong resilience lens. She developed two resilience-focused learning questions and addressed the first during the February learning meeting to allow the projects to apply what they learned during the training. Finally, Springer contributed to a blog post on Agrilinks showcasing the Fish Innovation Lab's climate resilience activities in Kenya and Bangladesh.

- 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.

Activity-related achievements related to climate resilience include:

- The Nigeria **Improving Biosecurity activity** contributes to resilience at the community, system, national, and regional level by using a cluster management approach that collectively reduces and spreads risk to reduce disease exposure. This is accomplished by addressing antimicrobial resistance through reduced antibiotic use and by contributing to an improved regulatory environment that can control the spread of disease without imposing undue regulatory burdens or costs on smallholder producers.
- The Kenya **Coral Reef Fishery Sustainability activity** is supporting fishing livelihoods in climate refugia in Kenya that are predicted to be less exposed to climate change impacts. The livelihood improvements resulting from the activity will therefore be sustainable in the

face of climate change because coral reefs in the climate refugia are unlikely to be affected by rising sea temperatures.

- 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. In FY22, fishermen reported increased income from the modified traps, and they are investing it in fishing and other enterprises, increasing their adaptive capacity.
- The Bangladesh **Harnessing Machine Learning activity** employs and promotes use of digital technologies, such as machine learning, remote sensing, smartphones, social media, open-source data collection, and video production software to collect, analyze, and communicate information to address climate change. 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, the team worked in the area of integrated rice-prawn/shrimp-vegetable farming. 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** is using a technology with potential to contribute to biodiversity conservation and make efficient use of scarce land and water resources to minimize effects of environmental shocks on livelihoods. Introduction of aquatic resources into an existing rice field also offers the immediate benefit of increased farm productivity 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.
- **Applying Lean Management in Aquaculture Production activity** in Nigeria contributes to resilience by improving farm and processing efficiency and thereby improving aquaculture production/productivity. The activity contributes to resilience on multiple levels by reducing the risk of production loss shocks.
- The **FishFirst! Zambia activity** purposefully designed trainings to have a strong component focused on resilience of value chains/households through training participants on potential income-generating microenterprise opportunities among women and youth entrepreneurs for producing and marketing dried fish powder and other dried food powders (dried orange-fleshed sweet potato powder, dried groundnut powder, etc.), and for 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 1) and in Appendix 2, the Fish Innovation Lab has 49 innovations that are at different stages of research, field testing, transfer, and uptake. This included 8 technologies in plant and animal improvement research, 27 in production systems research, and 14 in social science research. Overall, 17 technologies are in Phase 1: Under research, 14 are in Phase 2: Under field testing, 17 are in Phase 3: Made available for transfer, and 1 is in Phase 4: Demonstrated uptake by the public and/or private sector.

Innovations **Under Research** (Phase 1) include:

- **Plant and Animal Improvement Research**
  - Fish feed development technology (Nigeria Farm Diversification). Low-cost and good quality fish feeds are developed using locally available ingredients.

- Improvement of seeds and broods of experimental fish (Bangladesh Cryogenic Sperm Banking). Seeds of three Indian major carps (IMCs) and exotic carps will be produced using cryopreserved sperm in government and private hatcheries for improving their quality.
- Sensory Evaluation of Fish Product Training (Cambodia Fisheries & Food Processing). This video is to train personnel in Cambodia in the sensory evaluation technique of fish products.
- Genetically improved (Generation 1) catla families (Bangladesh Carp Genetic Improvement). A total of 201 (120 in FY21 and 81 in FY22) Generation 1 catla families were made and separately nursed for tagging and progeny testing.
- Genetically improved (Generation 2) silver carp families (Bangladesh Carp Genetic Improvement). In FY22, 240 Generation 2 silver carp families were made and separately nursed for tagging and progeny testing.

- **Production Systems Research**
  - Value addition-fish processing (Nigeria Farm Diversification). Value is added to fish harvested under integrated rice-fish system through smoking of fresh fish to extend the shelf-life, reduce food loss, increase margins of income, increase availability of fish for consumption all year round, and provide additional employment along the fish value chain.
  - Development of process maps to inform training, development, and technology deployment (Bangladesh Cryogenic Sperm Banking). Process maps for germplasm repository development and for the use and distribution of the germplasm, including training of the end users, are being prepared.
  - Development of training curriculum for intensive training and practice in the U.S. PI lab (Bangladesh Cryogenic Sperm Banking). A training curriculum on needs and tools necessary for repository development is intended to be delivered in a series of workshops that include theory and practice as well as demonstrations of commercial and open-source equipment and devices.
  - Sre Ambel River Fishery, Community Fisheries Assessment Tool: iFISH App (Cambodia Fisheries & Food Processing). A tool and App to analyze/visualize data was developed in R Shiny with four pages: Capture per Unit Effort (CPUE), length-frequency, species composition, and spatial characteristics (mapping of fishing areas and travel distances) of the Sre Ambel River fisheries.
  - Improved Crayfish Trapping System for Zambia (Zambia Crayfish). Traps for crayfish used in some areas are constructed of local reeds bound together by fibers from local riverbank reeds.
- **Social Science Research**
  - Lean Management Tools (Nigeria Lean Production Systems). Participants learned how to identify inefficiencies, reduce post-harvest losses, improve waste management, and decrease the cost of catfish and tilapia production in Nigerian aquaculture value chain activities and address the challenges using Lean management tools.
  - Cost-per-nutrient guide of select fish products and other animal source foods (ASF) (Nigeria Nourishing Nations). A cost-per-nutrient guide is being developed to identify the nutrient value of processed fish products in comparison to other ASF; this information will allow for an informed examination of the food environment in Nigeria.
  - Adoption Strategies in COVID-19 Policy Approach (Bangladesh Market Analysis). A policy approach was developed which aims at producing information that may be instrumental in designing action plans for facing COVID-19-like pandemic induced future challenges at both functional and policy levels.
  - Export Competitiveness Policy Approach (Bangladesh Market Analysis). A policy approach was developed to explore the shrimp export competitiveness of Bangladesh, China, India, Indonesia, Thailand, and Vietnam and investigate the factors influencing shrimp export competitiveness of Bangladesh considering different macroeconomic and policy variables.

- Trade Credit in Fish Farming (Bangladesh Market Analysis). A policy approach was developed to generate empirical evidence for whether trade credits are a drain or a gain in Bangladesh aquaculture and to explore the factors influencing farmers' decision to engage in trade credit contracts based on farm level economic data.
- Qualtrics Platform for Zambia Crayfish Impacts Survey (Zambia Crayfish). A survey of cray fisheries practices and basic post-harvest utilization was prepared.
- Fishery Length-Frequency Analysis/Stock Assessment (Zambia Crayfish). Length-frequency analysis is a standard method used by fisheries scientists to assess the status of fishery stocks. Shifting toward smaller predominant fish size classes is a strong indicator of overfishing.

Innovations **Under Field Testing** (Phase 2) include:

- **Plant and Animal Improvement Research**
  - Locally adoptable fish seed production techniques for African catfish and Tilapia (Nigeria Farm Diversification). Hatchery structures were developed that use facilities (hapas and fiberglass) available locally.
  - Production of quality fish seeds and broods using cryopreserved sperm (Bangladesh Cryogenic Sperm Banking). Seeds of three Indian major carps (IMCs) and exotic carps are produced using cryopreserved sperm in government and private hatcheries for improving their quality.
  - Genetically improved (Generation 3) rohu families (Bangladesh Carp Genetic Improvement). A total of 215 Generation 3 rohu families were made; they were separately nursed for tagging and progeny testing in FY22.
- **Production Systems Research**
  - Rice-Fish Farming (Nigeria Farm Diversification). The process was implemented of successfully introducing fish into rice fields for optimum production output/yield and resource-use efficiency. The focus is on technology uptake by rice and fish farmers and other interested investors.
  - Small-Scale Black Soldier Fly Production (Nigeria Farm Diversification). Low cost and nutrient-dense fish feed production is being developed through black soldier fly larvae production. The focus is on developing an innovative template for the use of BSF larvae as feed for fish under rice-fish integration.
  - Insects as Fishmeal Replacement (Nigeria Farming Insects). BSF farming represents a viable option for enhancing the productivity of small-scale aquaculture value chains in Nigeria.
  - Fisher Gear Modification (Kenya Samaki Salama). Locally fabricated traps were modified with an escape gap to reduce the number of immature fishes being captured, improve harvest efficiency, and promote sustainable fish populations.
  - Fisheries Harvest and Recovery Monitoring Protocol (Cambodia Fisheries & Food Processing). The protocol aims to document, visualize, and analyze artisanal fisheries data, including diversity, abundance, size distributions, fishing locations, and yield per effort.
  - Application of Lean Management in Aquaculture (Nigeria Lean Production Systems). Lean Management is designed to help value chain actors identify wastes, inefficiencies, and malpractices in their systems.
  - Red Cap (Nigeria Lean Production Systems). A database of information was developed for making management decisions based on Lean principles.
  - Atlan Collect Application (Kenya Coral Reef Fishery). The application is installed on mobile phones and used by trained community data collectors and county fisheries officers at the grassroots to monitor fish landings. It is designed to allow recording of fish weights by groupings and fishing effort plus prices of different fish groups by landing site.
- **Social Science Research**
  - Nutrition Social Marketing (Kenya Samaki Salama). The nutrition social marketing campaign includes regular communication of key messages across a range of

platforms including home visits, workshops, posters, calendars, banners, radio, t-shirts, stickers, flyers, cooking classes, and gatherings.
    - Training course for fish processor on Nutrition and Food Safety and Fish Processing/Handling (Nigeria Nourishing Nations). The course is for fish processors on nutrition to improve their ability to sell fish-based products to consumers, particularly women with young children. This training course includes seven low literacy modules teaching nutrition and food safety.
    - Complementary Food for Africa+Dried Fish Powder (ComFA+Fish) (FishFirst! Zambia). The key ingredient of the ComFA+Fish technology is locally sourced nutrient-dense small pelagic fish consumed whole (primarily in the form of dried fish powder), which is combined with other locally sourced nutrient-dense ingredients to fortify traditional staple foods.

Innovations that are **Made Available for Transfer** (Phase 3) include:

- **Production Systems Research**
    - Standard Operating Procedures (SOPs) on Fish Sampling Techniques for Disease Diagnostics (Nigeria Improving Biosecurity). The SOPs include clinical signs, fresh fish examination, bacteriology sampling, histopathology sampling, and molecular diagnostic sampling.
    - E-learning resources Learn.ink course 1: Fish epidemiology and health economics course using ODK, Learn.ink course 2: Fish sampling microlearning curriculum, and course 3: Syndromic surveillance course (Nigeria Improving Biosecurity). The tool comes with pre-online course modules developed on the Learn.ink platform. This approach will ensure wider use of the fish epidemiology and health economics tool for the collection of large data sets from different farming systems and geographies.
    - Smoking Tunnel for Fish (Cambodia Fisheries & Food Processing). A simple smoking tunnel was developed that can be built in villages to smoke fish and improve value, shelf life, and sensory quality.
    - Sample Preparation Techniques for Fish Nutrient Analysis (Cambodia Fisheries & Food Processing). Sample preparation by liquid nitrogen and grinding is used to preserve nutrients for chemical analysis.
- **Social Science Research**
    - Fish Epidemiology and Health Economics Survey Tool (Nigeria Improving Biosecurity). An online android mobile data collection tool was developed for farmer surveys to generate data on fish epidemiology and health economics.
    - Data Visualization Tools for Fishpond Identification (Bangladesh Machine Learning). An interactive online data visualization tool was developed that combines information extracted from remotely sensed images of Southwest Bangladesh and survey results to estimate aquaculture's multi-dimensional contributions to the economy and nutrition, focusing on production, economic value-added, and employment—all differentiated by gender and value chain segment.
    - Extension Video Trainings (Bangladesh Machine Learning). The project established a dedicated Bangla language YouTube channel. Short videos featuring innovative individuals, discussing their practices in their own words, were disseminated through social media channels to build capacity to adopt new technologies and speed up the uptake of improved practices among farmers and other value chain actors.

Innovations with **Demonstrated Uptake by the Public and/or Private Sector** (Phase 4) include:

- **Social Science Research**
    - Low-literacy tools to help women and youth fish processors better market their products (Nigeria Nourishing Nations). Tools include wristbands and hand fans with messages on the nutritional and health benefits of fish, developed and distributed to women and youth fish processors to educate their consumers and the public about the benefits of fish for human nutrition and to help them better market their fish products, thus strengthening their business and marketing skills.

Scaling Partnerships

As part of an agreement between the Government of Nigeria and WorldFish on transfer of Genetically Improved Farmed Tilapia (GIFT) from Malaysia to Nigeria, a new local partnership with the private sector to set up a GIFT multiplication and seed dissemination program in Nigeria is being developed under a Bill and Melinda Gates Foundation project. Capacity development of private sector partners on biosecurity, including sampling and testing for diseases, is being supported under this project, which is connected with the Fish Innovation Lab-funded Improving Biosecurity activity.

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. 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 submit their data upon completion of data collection, analysis, and publication of results. Teams use 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 and the Development Data Library and Harvard Dataverse.

Management Entity and Management Entity Partner Activities

The Fish Innovation Lab ME implements its research portfolio to achieve knowledge and technology adoption, scaling, and impact. The Fish Innovation Lab launched a competitive request for applications in April 2019. 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 FY 20, and six new commissioned studies and a buy-in were awarded in FY21. This section describes the activities the ME implemented in FY22 to support the new and ongoing research activities.

Support the Fish Innovation Lab research-for-development activities

In FY22, 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.

In FY22, the ME in coordination with the AOR organized meetings with four USAID missions (Bangladesh, Ghana, Nigeria, and Zambia), including the dissemination of findings and accomplishments. A virtual annual meeting was conducted in August 2022; it 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 ensures 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. In FY22, 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, target descriptions for each subaward, and actual indicators achieved to date in April 2022.

Learning agenda: The Fish Innovation Lab developed a learning agenda that has 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 development practices, particularly related to gender and youth inclusion, capacity building, 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 development best practices. The focus this period was ensuring participant engagement and buy-in for the three learning sessions held throughout FY22. For November, the objective was to establish, clarify, and implement learning themes and the specific sub-questions under the themes for FY22. For February, the focus was on stakeholder engagement and facilitating an interactive discussion on resilience to ensure projects accurately and enthusiastically applied resilience-focused interventions in their respective activities. For July, the focus was on scaling and adoption. During these meetings, the ME prioritized partner approaches for engaging national and local stakeholders in the development and implementation of technologies for scale. This included public and private sector stakeholders and primary end users, reliance on using existing social media platforms to disseminate/scale critical messages on technology adoption, and challenges to maintaining quality and ensuring sustainability during scaling. These discussions were followed by an interactive activity during the August Annual Meeting to improve Fish Innovation Lab partner understanding of the process, constraints, and pathways to sustainably move technologies from research and development to scaling and adoption. This activity allowed Fish Innovation Lab projects to contextualize their individual and collective scaling pathways through the lens of their primary end users.

The ME used a variety of facilitative methods towards achieving learning session goals, including pre-session surveys, preparation of presentations, and break-out rooms with facilitators and notetakers during live Zoom discussion sessions as well as in-depth consultations and applied learning activities.

A key lesson from this process was that despite the changes and clarifications to the MEL plan and PIRS, research activity leaders were unclear how to approach scaling and adoption, notably the constraints, process, and sustainability for the primary users. As a result, this drove the decision to pivot to the scaling and adoption focus of the July learning agenda and to hold a session during the Fish Innovation Lab Annual Meeting (August 2022) in which projects mapped out their respective scaling pathways, discussed the various considerations for project adoption, and identified potential end-user stakeholders.

Research strategy: The research strategy, distinct from the learning agenda, lays out the key research questions that will be addressed across regions and impact pathways by subaward research findings and development outcomes. In early FY21, Fish Innovation Lab research award teams, the ME Partners, and the EAB deliberated upon a set of 13 possible research questions that cut across multiple teams. While there was a consensus that the research strategy questions have merit and are relevant to the Fish Innovation Lab theory of change and funded research activities, three priority questions were identified for their relevance across multiple research activities/countries and inclusion of some of the narrower questions:

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)*

In FY22 activities that address the research strategy questions across teams and countries included:

- Dr. Iannotti and the Fish Innovation Lab 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 Dr. Shakuntala Haraksingh Thilsted gave opening remarks. The event highlighted four research activities from the Fish Innovation Lab that are testing 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, 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 Ghana Micronutrient Impact of Oysters in the Diet of Women Shellfishers activity, participated in the panel on "Women Shellfishers and Food Security in West Africa" (Area of Inquiry 3).
- In June 2022, the Feed the Future Innovation Lab for Fish and Aquaculture Africa Magazine jointly hosted a set of four webinars that unpacked important lessons from the Fish Innovation Lab's activities in Nigeria (Areas of Inquiry 1, 2, and 3).

Conduct a Self-Assessment

The ME commissioned a self-assessment of Fish Innovation Lab activities and ME performance. The self-assessment report will be used to improve ME operations and provide insights for strategic development of future research and capacity development activities. Data collection and analysis took place during the third and fourth quarter of FY22. A report will be finalized in FY23.

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. The following meetings and activities were attended:

- Participated in the Global Food Security Research Strategy: New Evidence and Opportunities webinar (October 2021)
- Presented at Aquaculture America 2022 in San Diego, CA (February 2022)
- Participated in Feed the Future Innovation Labs Research Community of Practice (March 2022)
- Participated in Feed the Future Innovation Labs Community of Practice on Gender AG meetings (March 2022, April 2022, May 2022, June 2022)
- Participated in Feed the Future Innovation Labs Local Capacity Development AG meetings (April 2022, May 2022, June 2022, July 2022)
- Participated in Innovation Lab Directors meetings (April 2022, May 2022, September 2022)
- Organized discussions on potential Fish Innovation Lab activities to support Sustainable Feed Strategy for Rice-Fish Activity in Nigeria (May 2022, July 2022)
- Hosted the Bangladesh Sector Meeting in Mymensingh to disseminate results from the five Fish Innovation Lab activities and to receive feedback and recommendation from Bangladesh stakeholders (July 2022)
- Held discussions on potential collaboration between Fish Innovation Lab and Post-Harvest Loss Innovation Lab to address the insect bioremediation opportunity in Tanzania (July 2022)
- Facilitated collaborations with Fish Innovation Lab Nourishing Nations activity and Cultivating New Frontiers in Agriculture (CNFA) (September 2022)
- Met with USAID Mission personnel in Zambia (December 2021), Nigeria (December 2021), Bangladesh (February/July 2022), Ghana (May 2022), Cambodia (May 2022), and Kenya (June 2022) to identify ways that the Fish Innovation Lab can assist the Missions in meeting their goals
- Conducted various check-in meetings with project team leaders throughout the year addressing administrative needs, programmatic adjustments, and/or financial issues
- Presented the Fish Innovation Lab Overview to various groups throughout the year to raise awareness and identify opportunities for potential collaborations
- Conducted various check-in meetings with project team leaders throughout the year addressing administrative needs, programmatic adjustments, and/or financial issues

Lawrence also serves on the Technical Working Group for the United Nations Food and Agriculture Organization program, “Progressive Management Pathway for Improving Aquaculture Biosecurity.” He participated in Technical Working Group meetings in FY22 and is collaborating with Melba Reantaso and Madan Dey to organize a technical committee for initiating Bangladesh as a pilot country for the program. Lawrence participated in a Food and Agriculture Organization technical working group meeting (June 26–July 2, 2022).

Stephen Reichley attended virtual meetings and served as a moderator. This included participating and moderating learning meetings for the Asia aquaculture, Africa aquaculture, and fisheries groups. He provided technical expertise as needed. 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 Aquaculture America 2022 in San Diego, California, U.S.A. and at the International Symposium on Aquatic Animal Health (ISAAH) in Santiago, Chile. He has presented the Fish Innovation Lab Overview to various groups throughout the year to raise awareness and identify opportunities for potential collaborations. Reichley was appointed Deputy Director of the Fish Innovation Lab in September 2022 and attended the Innovation Lab Directors meeting in Washington, D.C., USA.

Peter Allen represented and promoted the Fish Innovation Lab at a national/international conference, gave presentations, networked, attended a Fish Innovation Lab-sponsored presentation, and participated and served as a moderator for Fish Innovation Lab principal investigator reporting sessions. In addition, one international meeting (World Aquaculture Society

Egypt) was canceled after substantial preparation had been made due to an outbreak of a new variant (Omicron) of COVID-19. Conferences: Co-organized a 2-day symposium at the World Aquaculture Society meeting in San Diego, CA; organized, planned, chaired, and moderated a two-day session including a banquet; co-organizing a session at the Aquaculture America meeting in New Orleans, LA, U.S.A. in February 2023, planning is underway; Fish Innovation Lab ME service as a moderator at semi-annual and annual meetings.

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.

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

Kathleen Ragsdale and **Mary Read-Wahidi** supported the Fish Innovation Lab as the gender and youth equity specialist and co-specialist. They participated in the USAID Zambia Mission meeting and led and contributed to more than 25 gender/youth-related activities, with a focus on high-impact and open-access resources as well as collaborations across cross-cutting theme leads and across Innovation Labs. They also prepared for the upcoming GRADA-FIL Wave II roll out beginning in early FY23. More detail is provided in the gender and youth cross-cutting theme section above.

Laura Zseleczky supported the Fish Innovation Lab extensively through internal and external communications (see Communications below).

ME Partner – RTI International

RTI International supported the Fish Innovation Lab team in monitoring, evaluation, and learning (Rebecca Jeudin) as well as resilience (Joanna Springer). Notable FY22 activities included:

- RTI's primary goal for MEL-related work this period was ensuring participant engagement and buy-in for the three learning sessions held throughout FY22 in each of the three geographic zones. RTI conducted nine interactive learning sessions (three in November, three in February, and three in July).
- Revised the Monitoring, Evaluation, and Learning (MEL) Plan.
- Prepared the ME Core and Fish Innovation Lab Partner annual retreats and continued MEL support for all active research activities.
- RTI's participation in the ME Core and Fish Innovation Lab Partner annual retreats allowed MEL focused insight and contextualization of MEL activities as FIL completes Year 4 and begins the close-out activities of Year 5.
- RTI launched the online resilience training and reached out to three project teams for follow up consultations, developed a graphic mapping seven FIL projects to USAID's resilience framework, developed two resilience-focused learning questions, and contributed to a blog post on Agrilinks showcasing FIL's climate resilience 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. During this reporting period, TSU conducted the following activities:

- Successfully organized the Bangladesh Aquaculture Sector Meeting from July 24–28, 2022, an important opportunity for Bangladesh Fish Innovation Lab activities to present their research to key stakeholders in person in Bangladesh. The main purpose of the meeting was to disseminate results from the five Fish Innovation Lab activities in Bangladesh to

promote adoption and scaling of research findings and technologies as well as to receive feedback and recommendations from Bangladesh stakeholders. A total of 220 national and international participants, including large numbers of stakeholders, local fish farmers, and entrepreneurs, joined the meeting. Four ME members attended.
- Contributed to the successful initiation of seven Fish Innovation Lab activities in Asia.
- Informed the ME about issues and priorities from aquaculture and fisheries in Bangladesh and Cambodia, including keeping the ME abreast of COVID-19-related issues.
- Prepared and submitted monthly, semi-annual, and annual progress reports, including any other technical reports assigned by the ME for Bangladesh and Cambodia.

ME Partner – URI

During FY22, the URI ME Partner team (Elin Torell, Austin Humphries, Glenn Ricci, Karen Kent, Laura Skrobe, and Rachel Cohn) continued to support implementation of the Fish Innovation Lab-funded research-for-development activities as regional and cross-cutting theme specialists. The URI team supported the Fish Innovation Lab ME in the oversight of the different research for development activities as well as monitoring, evaluation, and learning. Achievements include:

- Provided individualized support to the research activities through periodic consultations and technical assistance (i.e., via PI check in meetings and topic specific meetings).
- Participated in the Innovation Lab cross-cutting theme Community of Practice, which focuses on gender and capacity development.
- Worked with Lora Iannotti to develop a Fisheries, Aquaculture, and Human Nutrition online course.
- Supported and participated in monthly ME partner meetings, PI meetings, learning agenda meetings, etc.
- Supported and participated in mission meetings with Nigeria, Zambia, Bangladesh, and Ghana.
- Implemented the Distant Water Fleets (DWF) buy-in activity, including obtaining mission concurrence for the four countries/regions of focus (Peru, Madagascar, Philippines, Pacific Islands region).
- Supported the research strategy implementation, including the submission of session abstracts to conferences.
- Organized and participated in the Fish Innovation Lab Annual Meeting in August 2022.
- Hosted the in-person ME retreat at URI in September 2022.
- Participated in innovation transfer and scaling discussions. Shared documents that URI developed as part of our FISH Malawi Project.
- Elin Torell was a co-author of a paper published by the Fish4Zambia team. The paper focused on gender. Torell provided feedback on the online gender courses and the summaries of the GRADA-FIL surveys. She was a member of the crosscutting theme Community of Practice.
- Austin Humphries was a co-author on two papers published by the Samaki Salama team. One paper focused on global contributions of fish to child nutrition, the other on complementary feeding practices in coastal Kenya for children. He monitored and assisted all the East Africa activity teams in accomplishing their goals for this period of performance and co-leads the DWF buy-in activity.
- Glenn Ricci launched the Fish Innovation Lab student network, engaged senior researchers, and organized four meetings during the reporting period. He is collaborating with Lora Iannotti to develop an online nutrition course.
- Karen Kent coordinated with Sunil Siriwardena on the West Africa activities. Kent is the Fish Innovation Lab point of contact for the pilot iReach Activity Tracker.
- Laura Skrobe and Rachel Cohn supported URI ME activities and served as a researcher on the DWF buy-in respectively.

ME Partner – WUSTL

Lora Iannotti served as the nutrition specialist, primarily provided technical inputs regarding nutrition and food security, a cross-cutting theme of the Fish Innovation Lab activities. During FY22, she supported the ME in the following ways:

- Published a manuscript in December 2021 in Food and Nutrition Bulletin, co-authored by others from the Fish Innovation Lab, on Aquatic Animal Foods for Nutrition Security and Child Health.
- With two members of her E3 Nutrition Lab and Dr. Brietta Oaks, designed and made progress on a systematic review to examine the evidence-base for the effects of mollusks and crustaceans on maternal and young child nutrition and health outcomes.
- Designed a narrative review paper on the role of fish and other aquatic foods in collaboration with the Global Alliance for Improved Nutrition (Gina Kennedy) and FAO (Molly Ahern).
- With the Fish Innovation Lab communications team, organized a Borlaug Dialogue Side Event: “Using Fish to Mitigate Malnutrition: Research to Test Innovative, Sustainable Approaches” on October 19, 2021.
- Organized a panel for the annual meeting of the American Public Health Association (APHA) in collaboration with Dr. Kathleen Ragsdale, featuring four Fish Innovation Lab activities directly related to fish and human nutrition.
- Made progress outlining the Nutrition Bait online course.
- Continued to serve as a voting member of the WHO Guidelines Development Group for complementary feeding of the breastfed and non-breastfed child.
- Participated in a retreat at URI from September 26–28, 2022.
- In February 2022, traveled to MSU to meet with ME members and project PIs.

Regional Coordinators and Regional Specialists

The three regional coordinators (M. Gulam Hussain, Andrew Wamukota, and Sunil Siriwardena) and regional specialists (Madan Dey, Austin Humphries, and Karen Kent) supported Fish Innovation Lab research activities in their respective regions. The regional teams are responsible for coordinating, monitoring, and technically advising all research activities by the Fish Innovation Lab in their respective regions. FY22 activity highlights include:

1. **Supported Fish Innovation Lab-funded research activities**. The Asia regional coordinator made field visits to Fish Innovation Lab-funded activity sites in the Mymensingh, Jashore, and Rajshahi regions in Bangladesh and traveled to Cambodia to meet the two project teams and visit their field sites. Hussain regularly contacted all lead/country PIs in Bangladesh and Cambodia via email and phone. Hussain provided aquaculture/fisheries support to teams in both Bangladesh and Cambodia, which included discussions regarding possible adaptation measures and resilience related to the COVID-19 pandemic. The East Africa team communicated with subawardees in Kenya and Zambia monthly and with the team in Malawi. The West Africa team supported the team in Ghana and continued supporting subawardees in Nigeria to facilitate solutions for challenges experienced.
2. **Connected with local stakeholders**. The Asia regional coordinator took a leadership role with the regional specialist in organizing the in-person Bangladesh Aquaculture Sector Meeting in July 2022 in Bangladesh. The Asia coordinator communicated regularly with in-country public sector organizations and institutions, such as the Department of Fisheries, the Bangladesh Fisheries Research Institute, universities, WorldFish, NGOs, and other stakeholders. The Asia coordinator kept the Fish Innovation Lab abreast of issues and priorities related to aquaculture and fisheries in Bangladesh and Cambodia. The East Africa team continued to maintain strong relationships with the Kenya Fisheries Service, Kenya Wildlife Service, and leaders and fishers in multiple beach management units along the coast in Kilifi and Kwale Counties. The West Africa coordinator facilitated connections between Fish Innovation Lab activities and local aquaculture producer organizations. He also connected the Fish Innovation Lab with the broader WorldFish activities in Nigeria. The

West Africa regional coordinator organized the Nigeria Sector Meeting in Nigeria, which took place in October 2022.

3. **Engaged in broader stakeholder outreach**. All of the coordinators participated in local meetings and workshops, where they represented the Fish Innovation Lab and made connections to local stakeholders and programs. The Asia regional coordinator participated in USAID Bangladesh and Cambodia Mission meetings.
4. **Acted as members of the Fish Innovation Lab ME Partner team**. As ME Partners, the regional coordinators and specialists attended monthly ME Partner virtual meetings, learning and research agenda sessions, the annual meeting, and other meetings. They prepared and submitted monthly, semiannual, and annual progress reports as well as other technical reports assigned by the Fish Innovation Lab ME.
5. **Produced publications and made presentations** relevant to the region. M. Gulam Hussain:
    - Attended and presented an oral aquaculture paper at the third International Sustainable Agricultural Intensification and Nutrition (SAIN) Conference (SAIN3) at Siem Reap, Cambodia.
    - Published a blog article titled “Impacts of COVID-19 Delta Variant on Fish Innovation Lab Activities in Bangladesh.”
    - Submitted a new blog article manuscript titled “Impact of COVID-19 Pandemic in Crab Farming for Women in Bangladesh.”

Communications

In FY22, 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 supported to contribute 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.
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. Six Fish Innovation Lab newsletters were distributed.
2. Materials such as success stories and briefs were developed and launched to showcase methods, technologies, and activities’ progress.
3. Key milestones were amplified via press releases, events, social media, website, and other channels.
4. USAID-led learning and sharing opportunities were tracked, and contributions were made to them as needed.

The Fish Innovation Lab uses its website as a conduit for distributing news releases and communications materials. All videos produced are available at https://www.fishinnovationlab.msstate.edu/media/videos. All blogs and news items are available at https://www.fishinnovationlab.msstate.edu/newsroom and https://www.agrilinks.org/activities/feed-future-innovation-lab-fish. The Fish Innovation Lab continued to use the Piestar platform for collecting and organizing monitoring data from research activities as well as sub awardee activities and achievements.

Six newsletters were distributed through the Fish Innovation Lab email list and website. A structured social media campaign was implemented to distribute success stories, briefs, and ad hoc material generated from subaward activities and partners. 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 the following stories in FY22 (all stories available at https://www.agrilinks.org/activities/feed-future-innovation-lab-fish):

- Fishers in Cambodia Use Citizen Science Program to Improve Their Fishery
- Integrating Digital Learning Tools for Long Distance Team Training During the COVID-19 Crisis
- Personalized Home Visits in Coastal Kenya Increase Knowledge on the Importance of Consuming Fish
- Increasing the Capacity for Achieving Sustainable Fisheries Management in Kenya
- Genetically Improved Rohu Carp is Now in the Hands of Bangladeshi Farmers
- Quality Seed Production Using Cryopreserved Sperm in Fish Hatcheries Becomes a Reality in Bangladesh
- Lean Subject Matter Experts Train Nigerian Fish Farmers to Improve Aquaculture Productivity
- Training Cambodian Fisheries Students and Faculty on Aquaculture to Build Capacity
- Nutrition and Food Safety Training Make a Difference for Nigerian Fish Processors
- The Fish Innovation Lab: Improving Livelihoods through Food Security Research
- Working from the Inside Out: How the Fish Innovation Lab Helps Partners Integrate Gender in Their Activities
- Innovations in Aquaculture Production and Fisheries Management Build Climate Resilience
- Aquaculture Training Teaches Bangladesh Farmers Business Practices to Be More Profitable
- Building Capacity: Graduate Student in Cambodia Working on the First Nutritional Database for Fish
- Learnings From the Feed the Future Innovation Lab for Fish in Nigeria
- Fish Innovation Lab Trainees Identify Areas of Waste and Make Improvements at the Farm Level
- Modified Fishing Traps and Fisher Workshops Promote Fish Consumption and Sustainable Fishing
- The Fish Innovation Lab Expands Its Reach to Four New Countries to Examine Impacts of Distant Water Fleets
- Safe Fish for Children and Expecting Mothers
- Individualized Nutrition Education and Group Cooking Demonstrations Increase Knowledge on Fish Consumption Among Caregivers
- Early Successes Inspire Fish Hatchery Owners to Adopt Cryopreservation Technology

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 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 experienced since 2020 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 the University of Ibadan (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.

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

In-country teams traveled to field sites and held more in-person meetings and training events, and investigators from 13 projects traveled internationally. In July, 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.

In spite of easing restrictions, the Fish Innovation Lab 2022 Annual Meeting was again held virtually instead of in person. The agenda was 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, maximizing the time in virtual sessions.

Other ME-Related Challenges

Despite continuous efforts from the management entity to support teams, the piloting of the integrated insect-to-fish farming activity in Malawi was not able to start activities on time such that the research goals could not be achieved in the remaining time frame. Therefore, the activity was closed in FY22.

The insect-to-fish activity in Nigeria faced challenges due to the lack of a functional feed mill in the study area. As a result, the study was redesigned. The new plan is to purchase black soldier fly larvae (BSFL), produce the fish feed in Ibadan instead of producing in the study area, and transport feed to Ebonyi and Cross River States. The team will conduct BSFL fish feed trials simultaneously with training and establishment of small-scale BSFL production, especially for women who will be connected to feed millers elsewhere to establish a market link.

One local partner experienced administrative challenges with DUNS number expiration and obtaining a Unique Entity Identification number.

Future Directions

The next steps for the awarded research-for-development activities are listed in Table 4.

Note: Some of these activities are dependent on the COVID-19 pandemic situation and may not occur if COVID-19 restrictions are reinstated. All projects and sub awards are scheduled to close out in FY23.

Table 4: FY23 Research Activities

Research Activities
1.1. Nigeria Aquaculture Diversification in Rural Communities activity • Completion of the second phase of rice-fish adaptation • Complete mid-term surveys (food and nutrition security, socioeconomics) • Train farmers on the rice-fish adaptation platform • Train farmers in fish breeding • Train farmers on black soldier fly larvae for fish feed • Train farmers on the use of fish smoking kiln • Conduct a national conference or workshop

Research Activities
• Data collation, analysis, and publications for the student's research • Compile a document on the farm diversification technological packages
1.2 Farming Insects in Nigeria activity ● Stock the fish tanks with fish juveniles ● Conduct baseline survey ● Establish the BSF colonies ● Data collection and analysis ● Reporting and publication
1.3 Nigeria Lean Production Systems activity ● Complete analyzing the data on the improvement in production efficiencies ● Finalize the report
1.4 Cambodia Bighead Catfish activity ● Describe research methods and activities ● Train the RUA personnel on (floating) feed manufacture ● Research contents are: 1) Determining protein and lipid (trial 1) requirement levels in grow-out stage under lab conditions; 2) Investigate the substitution of fishmeal (FM) by soybean meal (SBM) in the diet of Bighead Catfish (trials 2 and 3); and 3) developing feeding strategies for Bighead Catfish ● Exchange visit and Annual Meeting with project team and partners
1.5 Kenya Coral Reef Fishery Sustainability activity ● Fish catch monitoring: fish weighing, fish length monitoring, length-weight monitoring ● Establish fish catch monitoring in one remaining community in the seascape ● Submit the findings to peer review journal from this study ● Formulate repeat survey questionnaire ● Produce socio-economic publication
1.6 Bangladesh Cryogenic Sperm Banking activity ● Rear seeds in the selected hatcheries and fish farms in four regions ● Continue on-going sampling of fry in different nursing points ● Continue genetic characterization of broodstocks and their offspring using DNA microsatellite markers ● Arrange stakeholder training programs for dissemination of cryopreservation technology
1.7 Cambodia Fisheries and Food Processing activity For objective 1: ● Complete 24 months of fisheries data collection ● Bring fishers from Sre Ambel River, Koh Kong Province, to Pursat Province to exchange experiences with fishers already implementing a community-based management program ● Conduct stable isotopes analyses ● Complete fisheries data analyses For objective 2: ● Conduct a workshop where the smoker can be built to improve fish quality and shelf life ● Complete the proximate and fatty acid analysis to create a nutrition database for local Cambodian fish species

Research Activities
● Survey data and sensory panel data will give us ideal options for techniques of processing, preservation, and cooking methods to supply fish with the highest nutritional value while still being palatable to Cambodian residents ● Shelf-life study will be conducted following Chakriya and Champapao's travel to the United States for the most applicable preservation techniques to be communicated to the fishermen and fish vendors in Cambodia. This study will use natural antimicrobials and antioxidants to extend the shelf life of their fish products to reduce food waste caused by fish spoilage
1.8 Bangladesh Carp Genetic Improvement activity ● Output 3 Catla, rohu, silver carp brood development: Maintain candidate parents of the next generation of all three species ● Output 3 Catla and rohu (2021) progeny testing: Harvest-age assessment scheduled for late 2022 or early 2023 ● Output 4 Rohu (2020) SNP genotyping, analysis, and write-up: Submit paper by end of December 2022 ● Output 6 Cryopreserved sperm repository strategy for commercial carp genetic improvement and dissemination in Bangladesh: With university partners, initiate work on development of an implementation plan for backup and/or dissemination using cryopreservation. Report to be completed in Q1 of 2023. ● Output 1 Monitor/report on first release of genetically improved rohu to farmers at scale: Continue monitoring sales of G3 rohu to nurseries, traders, and farmers and estimate the number of farmers impacted in Q4 of 2022 ● Output 5 Negotiate with and train dissemination partners in accordance with business plan: Training is scheduled for 10 and 12th of October 2022. ● Output 2 Monitor/report on dissemination of 2022 spawn and business plan implementation: Monitor/report progress on factors affecting business plan implementation
1.9 Black Soldier Fly in Malawi ● Administrative close out
2.1 Nigeria Improving Biosecurity activity ● Work with project partners to finalize one epidemiology paper to submit to journal or for conference ● Using August 2022 project workshop outputs with national stakeholders and representatives from competent authorities, develop a draft outline for a national aquatic animal health strategy ● Draft best management practices (BMP) manual for farmer cluster management training ● Conduct training on molecular-based laboratory techniques (PCR, sequencing) ● Draft national aquatic animal health strategy document
2.2 Bangladesh Foodborne Pathogens activity ● Provide training on data analysis, interpretation, and thesis paper writing to the MSc students as a part of long-term capacity building ● Collect remaining whole fish samples from different stages of fish value chain including retail markets, wholesale markets, and grower ponds ● Analyze whole fish samples for *E. coli*, ESBL-producing *E. coli,* and predominant foodborne pathogens ● Submit manuscript on the findings obtained in year 1 ● Organize risk assessment training

Research Activities
2.3 Zambia Vaccines for Tilapia activity ● Confirmation of disease causation from a number of bacterial strains isolated from diseased fish, including *Lactococcus*, *Streptococcus*, *Klebsiella*, *Staphylococcus*, *Aeromonas,* and *Vibrio* ● Autogenous vaccine formulation
3.1 Bangladesh Harnessing Machine Learning activity ● The project has closed. Activities that will continue after project closeout include: the completion and publication of at least five more publications within 2023 and supporting research briefs. These will take the place of reports included in the original proposal.
3.2 Nigeria Nourishing Nations activity ● Complete the training program with women and youth fish processors ● Analyze fish product samples ● The UoC master's students complete their research proposals ● Submit three additional publications for peer-review
3.3 FishFirst! Zambia activity ● Continue work to produce technical briefs and news briefs for the Fish Innovation Lab and wider publications related to FishFirst! Zambia results ● Continue work to present FishFirst! Zambia results at relevant scientific conferences, seminars, webinars, meetings, and publications
3.4 Kenya Samaki Salama activity ● Having done community entry sensitization in Taita Taveta County ahead of the actual formative research, the next plan is to implement the qualitative research. This will involve conducting focal group discussions and key informant interviews with the fishermen, mothers/caregivers, health officers, fisheries officers, community health volunteers (in Taita Taveta County). ● Conduct a market survey to establish the fish value chain from the producer up to the consumer level in Taita Taveta County ● Do the qualitative reports of the formative research ● Analysis of quantitative and qualitative data will be ongoing in year 3 ● Extrapolate preliminary findings from the data collected and the research findings disseminated at different levels (the stakeholders at ministries of fisheries and health, as well as the participating communities) in Kilifi and Taita Taveta Counties ● Develop journal articles, conference abstracts, success stories, blog posts, and other forms of communication for dissemination of the project research findings
3.5 Zambia Crayfish activity ● Continue crayfish trapping studies in four sites in Kafue River and Lake Kariba ● Conduct harvest and utilization surveys, focus group discussions, and key informant interviews in Siavonga, Sinazongwe, Kafue, and Itezhi-Tezhi ● Conduct poll to assess presence or absence of crayfish country-wide in Zambia. ● Start to compile crayfish database in MS-Excel at UNZA, Lusaka
3.6 Bangladesh Market Analysis activity ● Analysis of the Household Income Expenditures Survey (HIES) data is in progress ● Hold a policy workshop in Dhaka in December 2022 to present the project findings to Bangladesh stakeholders ● Two more scientific articles are in progress

Research Activities
3.7: Ghana Micronutrient Impact of Oysters ● Complete oyster samples analysis for arsenic ● Complete analysis of the health risks of oyster consumption by calculating the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) for arsenic ● Prepare final report/manuscript

The next steps for the ME and ME Partners in implementing the FY23 Fish Innovation Lab work plan are listed in Table 5.

Table 5: Upcoming activities for the Fish Innovation Lab ME and ME Partners

Management Activities
Management Entity – MSU 1. Ensure financial accountability of research subawards and coordinate with the MSU Office of Sponsored Projects to manage subawards to institutions funded through the competitive Request for Applications and direct commission process. 2. Depending on COVID-19 travel restrictions, the ME will support Fish Innovation Lab activities in FY23 by traveling to countries to attend Fish Innovation Lab-related stakeholder and implementation meetings, meet with PIs and team members, and visit research sites. 3. Conduct virtual meetings with all PIs and Co-PIs for all activities. 4. Conduct the 2023 Fish Innovation Lab Annual Meeting in the U.S. The ME, ME Partners, AOR, EAB, and all subaward PIs will be invited. Subaward PIs are required to include a travel budget to attend the annual meeting in their subaward budgets. 5. Continue leading the Fish Innovation Lab communications efforts with website and social media maintenance, content generation, and dissemination for quarterly newsletters and feature articles. The ME also will maintain templates and other internal communications documents. 6. Members of the ME will continue to provide technical aquaculture expertise, support Institutional Animal Care and Use Committee (IACUC) regulatory compliance of activities, work to provide technical assistance to ensure productivity of activities, provide gender impacts and youth engagement expertise, support the research agenda and activities, and assist the director with document and presentation preparation. 7. Organize Mission meetings to increase awareness of Fish Innovation Lab activities and to explore opportunities for associate awards and buy-ins. 8. Visit minority-serving institutions and host webinars to strengthen relationships and build capacity. 9. Continue supporting the Fish Innovation Lab's implementation of activities related to gender equity and youth engagement. This will include offering additional open-access courses, developing outreach materials for Agrilinks and other platforms, and presenting the gender equity and youth engagement work at international conferences and meetings. It also includes: a. Completion of the third Gender Toolkit open-access course, "How to Build Your Own GRADA," which will be co-sponsored by the Feed the Future Soybean Innovation Lab, Feed the Future Innovation Lab for Fish, Gender Impacts Lab, and Mississippi State University.

Management Activities
b. Implement Wave II of the GRADA-FIL, a major activity of the Gender and Youth Engagement ME. Wave II of the GRADA-FIL is intended to be administered in the final year of Fish Innovation Lab-funded three-year projects. 10. Host a session at the Aquaculture America meeting in New Orleans, LA, U.S.A., in February 2023 titled, “Fish to Feed the World: Advancing Sustainable Solutions for Global Food Security.” 11. Reflect on future programming priorities and the potential for extension/follow-on. 12. Close out of funded research activities.
ME Partner – RTI International 1. Facilitate a series of discussions during the PI Meeting on resilience in November focused on project engagement of primary user group through their project activities and adaptations needed to guide these groups. 2. Lead groups in identification of the main shocks and stresses that can impact the sustainability and application of the technologies, approaches, and practices developed by the projects. 3. Hold three interactive learning sessions focusing on nutrition to align with USAID's current emphasis on the topic. 4. As a continuation of the learning theme on innovation/technology adoption and scaling, facilitate a series of discussions during the Year 5 Annual Meeting in February focusing on technology hand-off through the closeout process. 5. Guide the Fish Innovation Lab activities through the closeout process, assisting in tracker creation and information compliance with the ME team, ensuring project reporting on the key indicators and compliance with USAID’s Open Data Policy. 6. Contribute to a newsletter article and Agrilinks blog post on project-specific resilience activities.
ME Partner – TSU 1. Continue helping successful completion of the seven Fish Innovation Lab activities in Asia.
ME Partner – URI 1. Provide individualized support to research activities in East and West Africa through periodic consultations and technical assistance, including field visits as soon as international travel is possible. 2. Participate in the Innovation Lab cross-cutting theme community of practice. 3. Develop a Fisheries, Aquaculture, and Human Nutrition online course. 4. Support Fish Innovation Lab student network. 5. Support and participate in monthly ME partner meetings, PI meetings, learning agenda meetings, annual meeting, etc. 6. Support and participate in Mission meetings. 7. Attend and showcase the Fish Innovation Lab at virtual and in-person conferences and workshops. 8. Support research strategy implementation, including overseeing activities implemented under Area of Inquiry 3 (Human Outcomes).
ME Partner – WUSTL 1. Draft and submit a manuscript for systematic review to examine the evidence-base for the effects of mollusks and crustaceans on maternal and young child nutrition and health outcomes with Dr. Oaks, Dr. Iannotti, and Dr. Iannotti’s E3 Nutrition Lab members.

Management Activities
2. Draft and circulate the narrative review paper on the role of fish and other aquatic foods with the Global Alliance for Improved Nutrition and FAO to a larger group of co-authors. Fish Innovation Lab activities will be among the case studies used, including Samaki Salama and FishFirst! Zambia. 3. Support Dr. Gina Kennedy (now at the Global Alliance for Improved Nutrition) to present findings from Fish Innovation Lab projects at the International Union of Nutritional Sciences (IUNS-ICN, Japan, December 2022). 4. Hold the panel “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” (described above) at the Annual Meeting of the APHA on November 9, 2022. Dr. Iannotti will travel to Boston to participate in this panel. 5. Further develop the Nutrition Bait course.
Regional Coordinators 1. Participate in virtual platform meetings, research agenda meetings, and learning agenda sessions. 2. Communicate with lead/host country activity PIs to ensure successful implementation of activities, including monthly reporting. 3. Help facilitate and solve problems when issues arise related to activity implementation, particularly related to COVID-19. 4. Perform coordination and monitoring of Fish Innovation Lab-funded activities in their respective countries/regions. 5. Participate in Fish Innovation Lab ME Partners monthly and quarterly meetings and any other Fish Innovation Lab virtual meetings and webinars, such as EAB meetings. 6. Facilitate planning of virtual MEL reporting. 7. Prepare and submit monthly and quarterly progress reports. 8. Reach out to relevant government entities to share activity information and connect the activities to policymakers and other local stakeholders for innovation transfer and scaling. 9. Support activity close-out of Fish Innovation Lab-funded activities in their respective countries/regions.

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-US partner Award: $499,999
- Harnessing Machine Learning to Estimate Aquaculture Production and Value Chain Performance in Bangladesh. Lead PI: Ben Belton, Michigan State University. Award: $499,903 (Closed)
- 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
- Advancing Aquaculture Systems Productivity Through Carp Genetic Improvement. Lead PI: Matthew Hamilton, WorldFish. Non-US partner Award: $494,885
- 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
- Genome Sequencing and Development of Single Nucleotide Polymorphism (SNP) Markers from Rohu in Bangladesh. Lead PI: Attila Karsi, Mississippi State University. Award: $99,999 (Closed)

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-US partner Award: $496,126
- Increasing Sustainability of Fisheries and Aquaculture for Resilience of Cambodian Communities. Lead PI: Sandra Correa, Mississippi State University. Award: $417,095

Ghana

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

Kenya

- Achieving Coral Reef Fishery Sustainability in East African Biodiversity and Climate Refugia Centers. Lead PI: Timothy McClanahan, Wildlife Conservation Society. Award: $380,435
- 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
- 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 (Closed)

Malawi

- Piloting Integrated Insect-to-Fish (ITF) Farming Systems in Malawi. Lead PI: Jennifer L. Pechal, Michigan State University. Award: $99,800 (Closed)

Nigeria

- Aquaculture and Rural Communities: Integrated Agriculture-Aquaculture as Farm Diversification Strategy. Lead PI: Matthias Halwart, Food and Agriculture Organization of the United Nations. Non-US partner Award: $502,148
- 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-US partner Award: $597,153

- Improving Efficiency in the Nigerian Aquaculture Sector by Employing Lean Production Systems. Lead PI: Rohana Subasinghe, WorldFish. Non-US partner Award: $462,957
- 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
- Nourishing Nations: Improving the Quality and Safety of Processed Fish Products in Nigeria. Lead PI: Lauren Pincus, WorldFish. Non-US partner Award: $387,143
- 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 (Closed)

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
- Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia. Lead PI: Bernard Hang`ombe, University of Zambia. Non-US partner Award: $144,846
- Fish4Zambia: Assessing Facilitators and Barriers to Aquaculture and Fish Consumption in Zambia. Lead PI: Kathleen Ragsdale, Mississippi State University. Award: $99,879 (Closed)
- 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
- Replacing Fishmeal with Single Cell Proteins in Tilapia *Oreochromis niloticus* Diets in Zambia. Lead PI: Delbert Gatlin, Texas A & M University. Award: $98,883 (Closed)

Appendix 2: FY22 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**	**2021**	**2022**	**2022**
	Actual	**Actual**	**Target**	**Actual**
Sex				
Male	0	516	320	1,316
Female	0	262	115	895
Disaggregation not available	0	0	0	0
Totals	**0**	**778**	**435**	**2,211**
				Participant Type (multiple choices allowed)
Parents/Caregivers	0			388
Household Members	0	0	0	14
People in Government	0	47	0	221
USG-assisted Private Sector Firms	0	4	0	56
People in Civil Society	0	107	0	148
Producers	0	620	0	1,379
Not Applicable	0	0	0	5
Totals		**778**	**435**	**2,211**
Indicator Result Narrative	FY22 results for EG.3.2-1 reflect 39 short-term trainings conducted by research activities in FY22, reaching 2211 beneficiaries. This includes 60% males and 40% females (1,316 males and 895 females). These results reflect activities led by 13 research teams. These include training on Integrated Fish Farming - Benefits, Operational, and Management Procedures; Machine Learning to Identify Aquaculture Waterbodies; caregivers cooking demonstrations on how to prepare nutritious meals and retain nutrients that are commonly lost while cooking; and fish farmers training on scientific and business management practices.			
Deviation From Target	Targets for FY22 were set based on FY21 results, which assumed delays to the implementation of activities due to the ongoing COVID-19 pandemic. However, research teams were able to implement adaptations to accomplish trainings as countries began to implement better management and vaccination against COVID-19, allowing activities to implement effectively. Activities were able to expand on their host country expertise and increase travel for specific experts, which allowed them to reach a greater number of			

	qualified host country participants than was originally anticipated. As a result, FY22 actual indicator results surpassed the projected targets.

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

EG.3-2: Other project participants	2020 Actual	2021 Actual	2022 Target	2022 Actual
Gender				
Male	0	1,172	480	2,131
Female	0	601	221	2,050
Totals	**0**	**1,773**	**701**	**4,181**
				Age
15-29	0	442	194	1,302
30+	0	523	507	2,584
Disaggregation not available	0	808	0	295
Totals	**0**	**1,773**	**701**	**4,181**
				Participant Type (multiple choices allowed)
Parents/Caregivers	0	122	20	1,618
Household Members	0	30	0	55
People in Government	0	213	56	235
USG-assisted Private Sector Firms	0	54	69	327
People in Civil Society	0	311	93	380
Laborers	0	20	0	297
Producers	0	1,023	459	1,099
Not Applicable	0	0	2	170
Disaggregation not available	0	0	2	0
Totals	**0**	**1,773**	**701**	**4,181**
Indicator Result Narrative	FY22 results for EG.3-2 reflect over 50 workshops and events that occurred during this fiscal year. Activities reached 4,181 beneficiaries and almost achieved gender parity with 2,131 male (51%) and 2,050 female participants (49%). The beneficiaries were reached by interventions led by 16 Fish Innovation Lab activities. These included outreach workshops, stakeholder meetings on research studies, a fishers workshop on the use of modified traps with escape gaps, and a workshop on fish landing monitoring with stakeholders.			

Deviation From Target	Based on FY21 results, FY22 targets assumed ongoing implementation delays due to the ongoing COVID-19 pandemic. However, better management and vaccination against COVID-19 allowed activities to implement effectively. Activities were able to expand on their planned activities and reached greater numbers of qualified host country participants than was originally anticipated. This is also the result of the additional six activities added at the end of FY21. As a result, FY22 actual indicator results surpassed the projected targets.

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 Target	2022 Actual
Status				
Phase 1: Under Research	1	4	2	5
Phase 2: Under Field Testing	0	1	1	3
Phase 3: Made Available for Transfer	0	0	0	0
Phase 4: Demonstrated Uptake by the Public and/or Private Sector	0	0	0	0
Totals	**1**	**5**	**3**	**8**

EG.3.2-7: Production Systems Research	2020 Actual	2021 Actual	2022 Target	2022 (Q1-Q3) Actual
Status				
Phase 1: Under Research	1	4	0	5
Phase 2: Under Field Testing	0	10	6	8
Phase 3: Made Available for Transfer	0	0	3	14
Phase 4: Demonstrated Uptake by the Public and/or Private Sector	0	0	1	0
Totals	**1**	**14**	**10**	**27**

EG.3.2-7: Social Science Research	2020 Actual	2021 Actual	2022 Target	2022 Actual
Status				
Phase 1: Under Research	0	1	0	7
Phase 2: Under Field Testing	1	3	2	3
Phase 3: Made Available for Transfer	0	2	3	3

Phase 4: Demonstrated Uptake by the Public and/or Private Sector	0	0	0	1
Totals	**1**	**6**	**5**	**14**
Indicator Result Narrative	FY22 results for EG.3.2-7 reflect activities conducted by 14 research teams. This included 8 technologies in plant and animal improvement research, 27 in production systems research, and 14 in social science research. Overall, 17 technologies are in Phase 1: Under Research, 14 in Phase 2: Under Field Testing, 17 are in Phase 3: Made Available for Transfer, and 1 is in Phase 4: Demonstrated Uptake by the Public and/or Private Sector.			
Deviation From Target	While FY22 targets assumed ongoing delays to implementation due to the ongoing COVID-19 pandemic based on the FY21 actual results, the reality this year proved to be different. From the 25 technologies that were developed last year, many activities made additional developments to move them forward in the development phases. With the additional 6 new activities added last year, several were able to develop multiple technologies to forward the advancement of research developed under the Fish Innovation Lab. The Hamilton - Carp Genetic Improvement activity developed genetically improved Generation 1 catla families, Generation 2 silver carp families, and Generation 3 rohu families. The Dey - Market Analysis activity began the development of its Export Competitiveness and Trade Credit in Fish Farming approaches. Other projects with existing technologies also added to their repertoire, increasing the number of interventions under research such as the Halwart - Farm Diversification activity, which added locally adoptable fish seed production techniques for African catfish and tilapia and small-scale black soldier fly production to its innovations. As a result of these innovative approaches, the Fish Innovation Lab exceeded its planned targets for FY22.			

Number of Individuals in the agriculture system who have applied improved management practices or technologies with USG assistance (EG.3.2-24)

EG.3.2-24: Applied Tech	2020 Actual	2021 Actual	2022 Target	2022 Actual
Gender				
Male	0	145	15,000	1,031
Female	0	11	5,213	472
Not Applicable				270
Totals	**0**	**156**	**20,213**	**1,773**

				Age
15-29	0	45	5,000	326
30+	0	104	12,000	1,274
Not Applicable	0	7	3,213	173
Totals	**0**	**156**	**20,213**	**1,773**
				Technology Type (multiple choices allowed)
Wild-Caught Fisheries Management				732
Cultural practices	0	0	0	184
Wild fishing technique/gear	0	115	0	12
Aquaculture management	0	21	0	575
Disease management	0	3	0	55
Soil-related fertility and conservation	0	0	0	0
Water management-non-irrigation based	0	0	0	0
Climate mitigation	0	17	0	0
Climate adaptation	0	0	0	0
Marketing and distribution	0	0	0	31
Post-harvest—handling & storage	0	0	0	0
Value-added processing	0	0	0	0
Pest and Disease Management				84
Other	0	0	20,213	100
Totals	**0**	**156**	**20,213**	**1,773**
				Participant Type (multiple choices allowed)
Parents/Caregivers (Other)	0	2	0	9
Household Members	0	0	0	106
People in Government	0	8	0	135
USG-assisted Private Sector Firms	0	10	0	99
People in Civil Society	0	3	0	333
Laborers	0	0	0	0
Producers	0	133	20,000	1,091
Not Applicable	0	0	213	0
Totals	**0**	**156**	**20,213**	**1,773**

Indicator Result Narrative	FY22 results for EG.3.2-24 reflect activities conducted by research teams in the process of developing, testing, and making available for adoption new and improved technologies, approaches, and practices. Activities reached 1,773 beneficiaries applying technologies and practices under development under EG.3.2-7.
Deviation From Target	For FY22 the Fish Innovation Lab technologies projected a target of 20,213 beneficiaries reached through applied technologies. This was projected based on the launch of the Hamilton - Carp Genetic Improvement activity, which planned to develop Generation 3 (G3) rohu families and distribute them to 20,000 farmers, including poor producer households in FY22. This was based on FY21 estimates that ~3.5 tons of G3 spawn would be produced for distribution to nurseries/farmers by partner and non-partner multiplier hatcheries in mid-2022. However, engagement in the last few months of FY22 with hatcheries revealed disappointing growth of broodstock due to overstocking and suboptimal management in some cases, which likely negatively impacted spawn production. As a result, fewer hatcheries than anticipated spawned G3 rohu in 2022, meaning that few, if any, farmers received G3 rohu by the end of September 2022. As a result, the actual results from FY21 deviate from the target for this indicator.

Custom: Number of individuals who have received USG supported long-term agricultural sector productivity or food security training (Custom)

Long-term Training	2020 Actual	2021 Actual	2022 Target	2022 Actual
Gender				
Male	0	17	0	24
Female	0	14	0	18
Totals	**0**	**31**	**0**	**42**
				Training Status
Complete	0		0	10
Continuing	0	31	0	21
New	0		0	11
Totals	**0**	**31**	**0**	**42**

Indicator Result Narrative	During the FY22 period, the Fish Innovation Lab had 42 individuals/students (24 males and 18 females) who are currently enrolled in or have graduated from a bachelor's, master's, or PhD program receiving long-term training, mentorship, or apprenticeship in Fish Innovation Lab aquaculture, fisheries, resilience, and food-system activities. At the conclusion of the fiscal year, 21 individuals were continuing training to the next fiscal year, 10 completed degrees, and 11 new students were added. This includes 5 from the Cryogenic Sperm Banking activity, 2 from the Foodborne Pathogens activity, 3 from the Vaccines for Tilapia activity, and 1 from the Oyster Nutrition Activity.
Deviation From Target	NA

Appendix 3: Success Stories

Three Fish Innovation Lab success stories from FY22 are presented here.

1. Activity title: Increasing Sustainability of Fisheries and Aquaculture for Resilience of Cambodian Communities

   Lead PI: Sandra Correa, Mississippi State University

   Story title: Building Capacity: Graduate Student in Cambodia Working on the First Nutritional Database for Fish

   Story link: https://www.fishinnovationlab.msstate.edu/sites/www.fishinnovationlab.msstate.edu/files/inline-files/Thu%20Dinh-Increasing%20Sustainability%20of%20Fisheries%20and%20Aquaculture%20for%20Resilience%20of%20Cambodian%20Communities-Success%20Story%20FY22%20ml.pdf

2. 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

   Story title: Aquaculture Training Teaches Bangladesh Farmers Business Practices to be More Profitable

   Story link: https://www.fishinnovationlab.msstate.edu/sites/www.fishinnovationlab.msstate.edu/files/inline-files/Khan-Strategies%20for%20an%20Inclusive%20Aquaculture%20Value%20Chain%20in%20Bangladesh-Success%20Story%20FY22_final-draft_0.pdf

3. Activity title: Samaki Salama: Securing Small-Scale Fisheries in Kenya for Healthy Nutrition and Ecosystems

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

   Story title: Individualized Nutrition Education and Group Cooking Demonstrations Increase Knowledge on Fish Consumption Among Caregivers

   Story link: https://www.fishinnovationlab.msstate.edu/sites/www.fishinnovationlab.msstate.edu/files/inline-files/Samaki%20Salama%20project-cooking%20demonstrations%20success%20story-FY22.pdf

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, 2020, to September 30, 2022
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** Implementation of environmental best management practices 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 IACUC and environmental health and safety (EH&S) office or equivalent, as appropriate.	**Reporting** In consultation with the host community, the team cleared land in rice paddy areas, which were selected for the on-site adaptive plots. University of Ibadan PI facilitated training and guidance for proper construction of the on-site adaptive plot.
Activity Name: Cryogenic sperm banking of Indian major carps (*Catla*, *Labeo rohita*, and *Cirrhinus cirrhosus*) and exotic carps (*Hypophtalmichthys molitrix*, *Hypophthalmichthys nobilis*, and *Ctenopharyngodon idella*) for commercial seed production and brood banking **Sub-Activity:** Development of donor broodstocks of Indian major carps (IMCs) and three exotic carps **PI: Sarder**			

IEE Condition	Mitigation	Monitoring	Reporting
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.	• 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.	Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	Broodstocks of three IMCs (catla, rohu, and mrigal) of Halda and Padma river-origin were developed through rearing in broodstock ponds at BAU campus. Similarly, broodstocks of three exotic carps (silver carp, bighead carp, and grass carp) were developed by rearing recently imported fingerlings from China by the Department of Fisheries (DoF) in ponds at BAU campus. All the fish are being reared in confined ponds with supplementary feeds, and there is no risk of escaping to open water bodies.

Activity Name: Cryogenic sperm banking of Indian major carps (*Catla*, *Labeo rohita*, and *Cirrhinus cirrhosus*) and exotic carps (*Hypophtalmichthys molitrix*, *Hypophthalmichthys nobilis*, and *Ctenopharyngodon idella*) 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	Mitigation	Monitoring	Reporting
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 exotic species escaping to natural waters.	The team will adhere to good laboratory and biosafety practices. Seeds will be produced using cryopreserved sperm in hatcheries and will be 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.	Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	Seeds of six target species were produced using cryopreserved sperm in 17 government and private hatcheries in Mymensingh, Faridpur, Jashore, and Barishal regions and are being reared in the respective hatcheries and in a few technology adoption hatcheries and fish farms. Sampling of fry is done on a monthly basis. Seeds produced last year were reared in the hatcheries, and their sampling data showed comparatively higher growth in cryopreserved sperm-originated seeds of rohu, mrigal, silver carp, and bighead carp than their respective controls. Fin samples of seeds and their donor parents were taken and preserved for DNA analysis. The above activities do not have any risks to environment.

Activity Name: Cryogenic sperm banking of Indian major carps (*Catla*, *Labeo rohita*, and *Cirrhinus cirrhosus*) and exotic carps (*Hypophtalmichthys molitrix*, *Hypophthalmichthys nobilis*, and *Ctenopharyngodon idella*) 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 are stocked in four technology adoption hatcheries and fish farms and being reared. The growth performance of the seeds will be evaluated by collecting length and weight data through monthly sampling and compared with others. There are no negative effects of the above activities on 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

IEE Condition	Mitigation	Monitoring	Reporting
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.	• Implementation of environmental best management practices 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.	Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	The team took measures to reduce risks to a minimum. The activity is using plastic tanks for fish feeding demonstrations. They are properly constructed where wastewater drains easily and is not causing contamination.
Activity Name: Development and Investigation of the Delivery Mode of a Multivalent Bacterial Fish Vaccine in Zambia **Sub-Activity:** Clinical trials **PI: Hang'ombe**			
IEE Condition	**Mitigation**	**Monitoring**	**Reporting**
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.	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.	Documented staff training. Documented adherence to the appropriate protocols. Documented approval by the IACUC and EH&S office or equivalent as appropriate.	The laboratory has safety cabinets to ensure biosafety practices are followed with proper markings. The students prepare protocols before they are given the standard protocols. This is done to train them in laboratory management and protocol development. The students are trained in standard practices before undertaking laboratory usage.

Use of secured laboratories for pathogen isolation and animal experimentation.	Training provided to staff to ensure adherence to the regulations.		During field sampling, all disposable biological materials are placed in autoclavable bags for incineration at the university incineration facility. The materials are incinerated after autoclaving. The technical staff working with students are trained to handle biological and hazardous materials. This competence is approved through their registration by the Health Professionals Council of Zambia (HPCZ). The head of the department and chief scientist ensures all staff adhere to laboratory regulations using the code of conduct developed by the university.
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 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.	**Mitigation** • Implementation of environmental best management practices (BMPs) for agriculture and aquaculture. • Training provided to staff to ensure adherence to the regulation. • 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).	**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.

	• 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	Mitigation	Monitoring	Reporting
Negative determination with conditions: Activities should be evaluated to ensure that there are no risks related to: • Biosafety might be disrupted if invasive 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.	• Introduction of invasive alien fish species will be avoided. • Maintaining broodstock purity will be promoted, and 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.	• List of approved fish species to be promoted/developed. • Guidelines for maintaining the purity of broodstock developed. • 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.	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., 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, M.G., Mekkawy, W., Kilian, A., Benzie, J.A.H. 2019. "Single Nucleotide Polymorphisms (SNPs) reveal sibship among founders of a Bangladeshi rohu (*Labeo rohita*) breeding population." *Frontiers in Genetics* 10, no. 597 (2019). 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

		• Number of hatcheries that update the log sheets for recording day-to-day operations including waste management.	(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." *WorldFish,* (2021): 47. 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, 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. "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 6). 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 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.
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. Potential adverse environmental impacts of this activity include the unexpected promotion of unsustainable fishing practices.

PI: Correa

IEE Condition	Mitigation	Monitoring	Reporting
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.	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.	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).	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 is using the iFish Sre Ambel data visualization application to monitor the spatial extent of fishing areas. This allows the team to create a visual spatial analysis of fishing practices and detect unexpected changes in harvesting practices. The team completed the first twelve months of data collection by March 30, 2022. On August 30, 2022, the team completed data digitization and updated the iFish Sre Ambel App (https://ifish.shinyapps.io/ifish/) with the first year of data. The team conducted a visual spatial analysis of fishing practices. Based on the Fishing Trips Map, the team has not seen signs of change in harvest practices over the duration of the program.

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	Mitigation	Monitoring	Reporting
Category: analyses, studies, academic or research workshops and meetings. Research, extension, and capacity building should integrate and	Fishers will be trained in sustainable fisheries management. The importance of keeping fishing within the maximum sustainable yield will be emphasized.	Review of training curricula.	In FY21, modified traps with escape gaps were distributed, and the field team held monthly meetings with fishers who received traps to ensure proper use.

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.			In FY22, the team trained fishers in sustainable fisheries management and completed monitoring of the training curriculum. Data analysis is still underway to measure impact of gear modification, catch dynamics, and earnings.
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 environmental, health, and safety risks presented by fishing and coastal economic activities and appropriate choices and measures to manage these risks.	**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 fisheries measurements and management. • Conservation of marine resources and expected increase in fish production and incomes. • Benefits sharing from sustainable use of fisheries resources.	**Reporting** • Community fish biomass training involved 45 individuals from five communities and county government officers at the grassroots who learned how to evaluate fish biomass for the 19 fish families most often fished in eight sites within the Shimoni-Vanga seascape area. The activity involved fish biomass estimation in fishing areas, community closures, and government closures (Marin Park), enhancing their knowledge of the status of fish biomass and yield data in their fishing and non-fishing areas. In addition, the Wildlife Conservation Society (WCS) project team managed to train participants on how to record data directly on slates and had the opportunity to communicate feedback results of the data collated over the past years on social and ecological research within the transboundary conservation area. • The project team developed a fish biomass training manual in both English and Swahili languages that was to be used by community data collectors during the monthly fish landing data collection to serve as a reference in case of difficulty in fish identification while out in the field. In addition, the manual trained a few individuals who never had the opportunity to attend the training.

			• Underwater video clips and recorded video presentations on the status of Shimoni-Vanga seascape were shared with the communities during the fish biomass training activity and on the WCS social platforms (Fishers Forum Facebook page, WCS YouTube, and WhatsApp groups) to improve their knowledge and that of different stakeholders within the fishing sector on the status of fisheries within the area.
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 Category: analyses, studies, academic or research workshops and meetings. 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.	**Mitigation** Research, extension, and capacity building will integrate and promote general awareness of the environmental, health, and safety risks presented by fishing, onboard handling, and postharvest processing. It will integrate appropriate choices and measures to manage associated risks.	**Monitoring** Review and screening of research protocols, advocacy materials, and training curricula to ensure that they are environmentally sound.	**Reporting** Nothing to report. Data collection during two ComFA+Fish Taste-Test I-II Evaluations among 42 mothers and their 42 infants and young children did not have a negative environmental impact.
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 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.,	**Mitigation** 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.	**Monitoring** The activity will include a MEL indicator confirming that the activity recommended that fishers not fish above maximum sustainable yields.	**Reporting** Nothing to report. The first component of the training program focused on nutrition education and was completed. The remaining component of the training program will focus on extension activities promoting post-harvest loss and processing techniques and is planned for October 2022.

fuelwood) if message is poorly conceived and conveyed.			

Appendix 5: Climate Risk Screening and Management Report

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, 2021, to September 30, 2022
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 LGAs 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. Project 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, 2021, to September 30, 2022
				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 Indian major carps 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 where the broodstock will be developed. In the long-term, development of a cryogenic sperm bank for carp broodstock will enable climate resilience by	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, 2021, to September 30, 2022
		allowing selection for temperature tolerance or other environmental stressors.		
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	Natural weather patterns and slowly changing weather patterns and temperatures can impact the production area of a	Risks must be addressed on an individual basis.	Researchers will discuss potential climate risks with the resilience technical advisor, using USAID's Climate Risk	Consultations with regional teams indicate that climate-related changes in weather patterns do not affect fish supply or the availability of

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, 2021, to September 30, 2022
where these bottlenecks may be gender-related or affect youth in particular (Nigeria, Bangladesh, Zambia, Cambodia)	given standing crop of fish or crops of raw materials for fish feed.		Screening and Management Framework and adjust research as necessary.	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.
Improve sustainable fisheries management (Cambodia, Kenya)	Changes in sea or river temperatures may 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.	Capacity-building efforts and related research on developing sustainable fisheries management activities will consider relevant climate risks. .	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.	No updates in the reporting period relevant to changing sea or river temperatures. No severe weather events in project areas in coastal Kenya or Cambodia.
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.