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

IMPLEMENTATION PLAN 2013-2015

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USAID FROM THE AMERICAN PEOPLE   Oregon State University OSU   AQUAFISH INNOVATION LAB

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The mission of the AquaFish Innovation Lab is to enrich livelihoods and promote health by cultivating international multidisciplinary partnerships that advance science, research, education, and outreach in aquatic resources. Bringing together resources from Host Country institutions and US universities, the AquaFish Innovation Lab emphasizes sustainable solutions in aquaculture and fisheries for improving health, building wealth, conserving natural environments for future generations, and strengthening poorer countries' ability to self-govern.

Cover Photo
Fish farmer, Cambodia. Photo Courtesy of Tran Luong.

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INTRODUCTION

AquaFish received notification from USAID on 31 March 2013 of a five-year extension award to initiate new projects that build on past successes. A name change occurred with the funding extension, modifying the *AquaFish Collaborative Research Support Program* (AquaFish CRSP) to *Feed the Future Innovation Lab for Collaborative Research on Aquaculture & Fisheries* (AquaFish Innovation Lab). Five continuing but reconfigured projects from AquaFish CRSP responded to a Request for Proposals (RFP) for work in Asia and Africa. Continuing project principal investigators submitted proposals in early May and underwent an NSF-style external peer-review process along with a programmatic review involving USAID, the Nutrition Innovation Lab, and the AquaFish Management Team. In September 2013, AquaFish held an Orientation Workshop in Washington, DC with US Lead Project PIs and Host Country PIs from the five research projects. Individuals from USAID and the Bureau of Food Security (BFS) were invited to present information on the overall BFS Innovation Lab program, as well as on Monitoring and Evaluation, Human and Institutional Capacity Development (HICD), and USAID's Gender, Nutrition, and Environmental Strategies. These presentations served to inform and remind the PIs and the AquaFish Management Entity about reporting policies for USAID-funded projects.

The five core research projects described herein represent all of the key regions, themes, and topic areas called for in the third AquaFish RFP, issued in 2013 by Oregon State University (OSU), which serves as the Lead Institution for the overall AquaFish Innovation Lab. As a group, these projects include 10 countries, 11 US universities, and 20 Host Country (HC) institutions in formal funded partnerships. The five projects contain 34 investigations accounting for over US $3 million from the USAID, not including management costs or other outreach expenditures. Each project additionally targets 40% in matching funding for each federal dollar received.

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

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

USAID (May 2013, RFP) looks to the AquaFish Innovation Lab to "develop more comprehensive, sustainable, ecological and socially compatible, and economically viable aquaculture systems and innovative fisheries management systems in developing countries that contribute to poverty alleviation and food security."

The overall research context for the projects described in this *Implementation Plan* is poverty alleviation and food security improvement through sustainable aquaculture development and aquatic resources management. Discovery through innovative research and technology development forms the core of the projects. Knowledge and information is transferred through institutional strengthening, outreach, and capacity building activities such as training, formal education, workshops, extension, and conferences. Research presented in this plan addresses the following key elements:

- The health and nutrition needs of our target communities, particularly women and children;
- Natural resource management, climate change, and biodiversity issues with targeted activities that protect native fisheries and the integrity of local and regional water systems; and
- Market development by linking small producers to markets and training rural stakeholders in food safety and food quality standards.

As part of the new USAID Feed the Future Food Security Innovation Center, AquaFish operates under the Program for Research on Nutritious and Safe Foods, which "addresses undernutrition, especially in women and children, by increasing the availability and access to nutrient dense foods through research on horticulture crops, livestock, fish and dairy, food safety threats such as mycotoxins and other contaminants and on household nutrition and food utilization" (R. Bertram, 7 December 2012).

AQUAFISH GLOBAL PROJECT THEMES (GOALS)

Each project focuses on one of the following primary AquaFish theme and integrates all four themes to achieve a systems approach:

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

The global themes are cross-cutting and address several specific USAID policy documents and guidelines, including the US Government's Global Hunger and Food Security Initiative, *Feed the Future* (FTF), in the areas of *inclusive agricultural growth* and *improved nutritional status of target populations* (www.feedthefuture.gov). Project themes also address global initiatives and strategies that relate to the overall program goal.

USAID also encourages AquaFish to address biodiversity conservation and non-GMO biotechnology solutions to critical issues in aquaculture. Each overall project describes a comprehensive development approach to a problem. Projects are formed around *core program components*, as identified by USAID:

- A systems approach
- Social, economic, and environmental sustainability
- Capacity building and institution strengthening
- Gender integration
- High quality research with a pathway for outreach, dissemination, and adoption
- Food security with a focus on the poor
- Climate change

AQUAFISH TOPIC AREAS

AquaFish core projects have work plans (investigations) organized around ten specific areas of inquiry, called Topic Areas. Topic areas pertain to aquaculture and the nexus between aquaculture and fisheries. AquaFish projects, each containing five to eight investigations, address more than one topic area in describing aquaculture research that will improve diets, generate income for smallholders, manage environments for future generations, and enhance trade opportunities.

A systems approach requires that each AquaFish project integrates topic areas from both *Integrated Production Systems* and *People, Livelihoods, and Ecosystem Interrelationships*. Each investigation in this *Implementation Plan* has been assigned a single topic area that best describes it. Some of the following topic areas overlap and are interconnected. The topic area descriptions are provided for illustrative purposes and are not prescriptive.

Integrated Production Systems

Production System Design and Best Management Alternatives (BMA)

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

Sustainable Feed Technology and Nutrient Input Systems (SFT*)*

Methods of increasing the range of available ingredients and improving the technology available to manufacture and deliver feeds are a critical research theme. Better information about fish nutrition can lead to the development of less expensive and more efficient feeds. Investigations on successful adoption, extension, and best practices for efficient feed strategies that reduce the "ecological footprint" of a species under cultivation are encouraged. Research on soil-water dynamics and natural productivity to lessen feed needs were fundamental to the PD/A and ACRSPs; critical new areas of research may be continued, along with outreach to poor farmers using low- cost, no/low-feed technologies. Feed research that lessens reliance on fishmeal/proteins/oils and lowers feed conversion ratios is desired, as is research on feeds (ingredients, sources, regimes, formulations) that result in high quality and safe aquaculture products with healthy nutrition profiles. Complex pond dynamics technologies need to be simplified for use by new farmers; improved applications of pond dynamics technologies for driving non-fed plankton-driven systems is applicable where access to feeds is expensive or unreliable.

Climate Change Adaptation: Indigenous Species Development (IND)

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

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

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

Food Safety, Post Harvest, and Value-Added Product Development (FSV)
Ensuring high quality, safe, and nutritious fish products for local consumers and the competitive international marketplace is a primary research goal. Efforts that focus on reducing microbial contamination, HACCP (Hazard Analysis and Critical Control Point) controls and hazards associated with seafood processing, value-added processing, post-processing, and by-product/waste development are of interest. Consumers and producers alike will benefit from research that contributes to the development of standards and practices that protect fish products from spoilage, adulteration, mishandling, and off- flavors. Processing waste can claim up to 70% by weight of finfish depending on the species and manner processed, and post harvest losses can claim around 30%. Partnering with other groups and co-developing outreach techniques to reduce post harvest losses can significantly contribute to the amount of fish available for consumption; thus, contributing to the nutrition goals of USAID's Feed the Future Initiative. Certification, traceability, product integrity, and other efforts to improve fish products for consumer acceptance and international markets are desired. Gender integration is important to consider as women are strongly represented in the processing and marketing sectors, and throughout much of the value chains. (Aquaculture-Fisheries Nexus Topic Area)

Policy Development (PDV)
Policy initiatives that link aquaculture to various water uses to improve human health are needed. Areas of inquiry can include institutional efforts to improve extension related to aquaculture and aquatic resources management; science-based policy recommendations targeting poor subpopulations

within a project area, or more broadly (for example, national aquaculture strategies); methods of improving access to fish of vulnerable populations including children (e.g., school-based aquaculture programs); science-based strategies for integrating aquaculture with other water uses to improve wellbeing, such as linkages with clean drinking water and improved sanitation. Additionally, social and cultural analyses regarding the impacts of fish farming may yield critical information for informing policy development.

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

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

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

INVESTIGATIONS

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

Experiment A scientifically sound investigation that addresses a testable hypothesis. An experiment implies collection of new data by controlled manipulation and observation.

Study A study may or may not be less technical or rigorous than an experiment and may state a hypothesis if appropriate. Studies include surveys, focus groups, database examinations, most modeling work, and collection of technical data that do not involve controlled manipulation (e.g., collection and analysis of soil samples from sites without having experiments of hypothesized effect before collection).

Activity An activity requires staff time and possibly materials but does not generate new information like an experiment or a study. Conference organization, training sessions, workshops, outreach, and transformation and dissemination of information are examples of activities.

Investigations provide a transparent means for evaluating different types of work under AquaFish, be it quantitative, empirical, biologically-based, qualitative, policy-based, or informal.

Criteria for Outreach and Gender Integration

As required, each project includes at least one experiment or study, as well as outreach activities such as training, formal education, extension, and conference organizing. Each project also includes at least one outreach *activity* focused on women and/or girls. In addition to the individual investigations focused on gender and outreach, each AquaFish project developed an *Outreach and Dissemination Plan* and a *Gender Inclusiveness Strategy* as follows:

- *Outreach and Dissemination Plan*. The outreach plans describe activities, methods, a timeline, and a list of deliverables for effectively communicating and disseminating research findings to target audiences. Capacity building is critical to an effective dissemination strategy; therefore, AquaFish seeks to build capacity of HC researchers, farmers, and other stakeholders through improved understanding of aquaculture technologies (including soft technologies such as best practices and knowledge-based systems, as well as hard technologies).
- *Gender Inclusiveness Strategy*. The gender plans outline how each project will address and advance the overall AquaFish Gender Strategy of collecting and analyzing disaggregated gender data, monitoring and evaluating gender integration over the life of the project, and reaching the 50% benchmark for training women in formal and informal education by promoting the participation of women in education and training opportunities provided through AquaFish funding. Each *Gender Inclusiveness Strategy* was reviewed by USAID and the AquaFish Management Entity, and revised accordingly.

PROGRAM REGIONS

Projects were selected that focused on established AquaFish Host Countries in Asia and Africa and overlap with emerging interest areas of AquaFish. The eight Host Countries include: Ghana, Tanzania, Kenya, Uganda, Bangladesh, Nepal, Vietnam, and Cambodia (all projects focus on at least one USAID-FTF Focus Country). Proposed activities received USAID country-level concurrence prior to award. Attention was paid to projects aimed at strengthening existing countries' infrastructure to build on previous USAID investments. Project proposals were evaluated based on the strength of linkages to host countries, among other criteria. Projects extend supportive activities to nearby countries within the same region. Existing AquaFish relationships are utilized throughout the core research projects.

RULES OF CONDUCT

Rules of conduct are described in greater detail in each project's subcontract with the Management Entity and in other program documents. The following subset of rules is particularly relevant to the *Implementation Plan*.

Fostering Respectful Partnerships

Projects aim to foster linkages with organizations including US minority-serving institutions, non-governmental organizations (NGOs), national agricultural research institutions, other Innovation Labs and Collaborative Research Support Programs (CRSPs), international centers, private businesses, and others as desired. Projects that link Host Country researchers from one Innovation Lab site to another are encouraged. US and Host Country PIs share in budgetary decisions and overall priority setting for the project, as well as in other collaborative activities related to the Innovation Lab. Proposals, work plans, and project budgets must be developed collaboratively between HC and US researchers. US PIs must actively establish an effective working relationship with the ME and other Innovation Labs/CRSPs, US and Host Country PIs, and program participants.

Memoranda of Understanding

Within three months of award notification, the Lead US Institution of each project is required to enter into Memoranda of Understanding (MOUs) with institutions at Host Country sites. MOUs with existing institutions will need to be renewed and filed with the Management Office (MO). Subcontracting US institutions may also enter into MOUs with HC partners to strengthen institutional relationships and streamline administrative processes. MOUs between Host Country institutions are not discouraged but will not take the place of MOUs between US and Host Country institutions. MOUs must provide the opportunity for other AquaFish projects to function under the authority of the agreement and must provide for joint authorship of reports and site visits at the discretion of the AquaFish Management Entity. Draft MOUs with new institutions are submitted to the MO for review prior to execution.

Environmental Compliance

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

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

Fund Matching and Distribution

At least 50% of funds must be expended in or on behalf of the Host Country or region. Each project must supply an additional 20% of US non-federal matching funding from participating US entities and target 20% from participating HC institutions. Collaborative efforts that involve undergraduate students, graduate students, and post-doctoral fellows are encouraged. AquaFish funds will not be used to support US expatriate personnel or consultants, as the Innovation Lab model is intended to build institutional networks and capacities. In furtherance of the Title XII initiative that authorizes all Innovation Labs, projects must demonstrate return benefits to the US. Under Title XII, AquaFish has responsibility to provide mutual benefits and discoveries that can apply to the HC region and US, and that will support future development of sustainable aquaculture and fisheries.

RESEARCH PRIORITIES

All five projects address the following general research priorities:

- **Priority Ecosystems -** Inland and coastal ecosystems for aquaculture and aquaculture-fishery nexus topic areas.
- **Priority Species -** Low-trophic level fishes; domesticated freshwater fishes; non-finfishes (e.g., bivalves, seaweeds); aquatic organisms used in polycultures and integrated systems; native species. Food fishes are a priority but species used for non-food purposes (e.g., ornamental, pharmaceutical) may also be included as a priority if they are a vital part of an integrated approach towards food security and poverty alleviation.
- **Target Groups -** Aquaculture farms (small- to medium-scale, subsistence, and commercial) and aquaculture intermediaries, policy makers, and others in host countries.
- **Key Partners -** Universities, HC and US government, NGOs, private sector, Consultive Group on International Agricultural Research (CGIAR), and the USAID Food Security Innovation Center.

PART I. RESEARCH PROJECT SUMMARIES

LEAD US UNIVERSITY: NORTH CAROLINA STATE UNIVERSITY

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Project Title

ENHANCING AQUACULTURE PRODUCTION EFFICIENCY, SUSTAINABILITY AND ADAPTIVE MEASURES TO CLIMATE CHANGE IMPACTS IN BANGLADESH

AquaFish Project Theme

ENVIRONMENTAL MANAGEMENT FOR SUSTAINABLE AQUATIC RESOURCE USE INCOME GENERATION FOR SMALL-SCALE FISH FARMS

Investigations

13SFT04NC	Economic and Environmental Benefits of Reduced Feed Inputs in the Polyculture of Tilapia and Major Indian Carps
13SFT05NC	Pulsed Feeding Strategies to Improve Growth Performance, Gastrointestinal Nutrient Absorption Efficiency, and Establishment of Beneficial Gut Flora in Tilapia Pond Culture
13MNE01NC	Novel Approach for the Semi-Intensive Polyculture of Indigenous Air-Breathing Fish with Carps for Increasing Income and Dietary Nutrition While Reducing Negative Environmental Impacts
13BMA02NC	The Culture Potential of Pangasius Catfish in Brackish (Hyposaline) Waters of the Greater Barishal Regions in Southern Bangladesh
13HHI03NC	Integrated *Mola* Fish and Gher/Freshwater Prawn Farming with Dyke Cropping to Increase Household Nutrition and Earnings for Rural Farmers in Southwest Bangladesh
13BMA03NC	Production for Nutrient-Rich Small Fish *Mola* and Freshwater Prawn Using Integrated Cage-Pond/Carp Polyculture for Northwest Bangladesh
13MER04NC	Improving Nutritional Status and Livelihood for Marginalized Women Households in Southwest Bangladesh Through Aquaculture and Value Chain Analysis

US and Host Country Institutions

US	North Carolina State University
Bangladesh	Bangladesh Agricultural University
	Khulna University
	University of Dhaka
	Hajee Mohammed Danesh Science Technology University

Other Collaborations and Linkages

Southeast Asian Development Center, Philippines

Project Summary

We propose a series of studies to enhance aquaculture production efficiency, sustainability, and adaptive measures to climate change impacts in Bangladesh through improved management of aquatic resources. Development of improved aquaculture production practices will provide additional yields of nutritious seafoods, improved income earnings for impoverished households and in communities impacted by global climate change, and reduce degradation of environmental water quality (nutrient loading). These project goals, a majority of which will be centered in the South, align well with Bangladesh's national health and food security policies and USAID's Feed-the-Future priorities for Bangladesh. The research proposed utilizes reduced feed inputs and mixed trophic polyculture strategies to mitigate poor water quality while enhancing more sustainable production of tilapia and nutrient-dense indigenous, high-value Shing/Koi at lower costs. Increasing the depth of ponds and improving best management practices will enhance shrimp yields while mitigating problems with disease and more extreme climatic temperatures. Evaluating the tolerance and production potential of fish in low saline waters can provide a means for coastal communities to cope with sea level rises and losses in the culture of traditional freshwater species. Integration of dyke vegetable farming using nutrient-rich pond muds, derived from polyculture of small indigenous fish (Mola) and prawn, can provide a means for producing fish and vegetables high in nutritional value for household consumption and prawns for income generation. Increasing the density of Mola in polyculture can also provide greater quantities of micronutrient-dense fish, high in vitamin. We shall also provide training targeted to impoverished women on better management practices for fattening of crab in the coastal Southwest region. This along with a value chain analysis can identify how the industry can be further developed for their economic benefit.

Aqua-foods are an important source of nutrition, comprising > 60% of the dietary protein, for the Bangladesh population. Studies show improvements in dietary nutrition and educational awareness can be achieved through modest increases in household income (FAO, 2012). Implementations of strategies that reduce feed inputs, or those incorporating mixed-trophic polyculture, are directly targeted to increasing fish yields and reducing production costs for farmers. This, along with the other culture technologies proposed which are anticipated to produce similar efficiencies, should increase seafood consumption and income generation and improve the nutritional well being of families. In two of the investigations we target fish that are particularly high in nutrient value, Shing/Koi and Mola. These fishes have high levels of vitamin A, iron, calcium and zinc and their consumption can provide improved nutrition to children and women of rural Bangladesh, who frequently suffer from vitamin A deficiency and iron-deficient anemia. Mola are self-recruiting species that can be harvested periodically throughout the prawn production cycle. When this polyculture system is integrated with land-based dyke vegetable production, these added crops provide a steady source of nutritious foods that can be directly consumed by households instead of being sold at market. This project will also evaluate if fish and vegetable consumption increased in households where integrated Mola/freshwater prawn and gher/farming with dyke cropping is implemented.

Our research will integrate with other FTF USAID Bangladesh projects, largely undertaken by our collaborator CGIAR-WorldFish. These include the "Feed the Future Aquaculture Project", "Expansion of Cereal Systems Initiative for South Asia (CSISA)", Greater Harvest and Economic Returns from Shrimp (GHERS) initiative under the "Poverty Reduction by Increasing the Competitiveness of Enterprises" program (PRICE), as well as the "Save the Children - Nobo Jibon Multi-year Assistance Programs (MYAPs)". These projects are aimed at improving fish and shrimp seeds that include identification of pathogen free shrimp and promotion of its distribution, policy reform and institutional capacity for better fish seed and fish feed quality, promoting fish culture in ghers or traditional rice growing systems, evaluating culture of salt-tolerant species, and large-scale dissemination of the latest methods for carp/small fish polyculture, cage aquaculture, prawn aquaculture, and aquaculture nurseries. Our proposed investigations will assess and provide new and improved aquaculture management technologies that can be integrated with these programs and scaled up for dissemination to and adoption by farming households.

LEAD US UNIVERSITY: UNIVERSITY OF CONNECTICUT AT AVERY POINT

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Project Title

IMPROVING FOOD SECURITY, HOUSEHOLD NUTRITION, AND TRADE THROUGH SUSTAINABLE AQUACULTURE AND AQUATIC RESOURCE MANAGEMENT IN CAMBODIA AND VIETNAM

AquaFish Project Theme

ENHANCED TRADE AND INVESTMENT FOR GLOBAL FISHERY MARKETS

Investigations

13MER03UC	Impacts of Climate Change on Fish Value Chains in the Lower Mekong Basin of Cambodia and Vietnam
13SFT03UC	Alternative Feeds and Processing for Freshwater Aquaculture Species
13IND02UC	Sustainable Snakehead Aquaculture Development in the Lower Mekong River Basin of Cambodia
13WIZ01UC	Estimating Carrying Capacity for Aquaculture in Cambodia
13HHI02UC	Enhancing Food Security and Household Nutrition Vulnerability of Women and Children Focus on Nutrient Dense Commonly Consumed Fish from Capture Fish and Aquaculture in Cambodia
13PDV01UC	Policy Recommendations to Improve Food Security and Household Nutrition Through Sustainable Aquaculture and Aquatic Resource Management in Cambodia and Vietnam

US and Host Country Institutions

US	University of Connecticut at Avery Point
	University of Rhode Island
Cambodia	Inland Fisheries Research and Development Institute
Vietnam	Can Tho University

Project Summary

Fish is a key source of animal protein, fatty acids, vitamins, and micronutrients like iron and zinc that contribute to a balanced diet, and is a particularly important food source in many developing countries. In some of Asia's poorest countries (Bangladesh and Cambodia, for example) people derive as much as 75% of their daily protein from fish. Sustaining and increasing fish consumption in low income, food deficient countries where it is a preferred food source is important because of the protein they provide and the range and bioavailability of the nutrients that many fish species contain. The goal of this project is improved nutrition, poverty alleviation and food security through sustainable aquaculture development and aquatic resources management in Cambodia and Vietnam; especially in the context of links between trade and markets and climate change. This goal takes into account the need to address malnutrition, especially in women and children, by increasing the availability and access to nutrient dense foods through research on fish. This goal aligns with the Feed the Future (FTF) Initiative and FTF Research Strategy and the Program for Research on Nutrition and Safe Foods to address undernutrition, food safety and food security, especially of vulnerable populations (women and children). The proposed project will explore links between nutrition, food security, income, livelihoods, markets, trade and women and aquaculture by examining consumption and household nutritional security and aquatic product value chains.

Specifically, Investigation 1 address human nutrition through an analysis of the impacts of climate change on fish value chains; Investigation 2 through improved availability of snakehead fish using a formulated feed and improved processing activities for added value of cultured snakehead products, particularly for women; Investigation 3 through sustainable snakehead aquaculture in Cambodia; Investigation 4 through ecosystem planning for sustainable aquaculture production in Cambodia; Investigation 5 through assessing the impacts of climate change on fish yields and on fish consumption and food security of vulnerable populations, with a focus on women and children; and Investigation 6 through science based policy recommendations to government on climate change adaption strategies to maintain nutrition and food security.

In Cambodia, the proposed project will complement the ongoing Feed the Future and Global Climate Change initiatives of the HARVEST project on aquaculture which is improving nutrition, income, and resilience for 70,000 rural, smallholder Cambodian households, developing agricultural solutions to address poor productivity, post-harvest losses, food safety, lack of market access, environmental degradation, and the effects of climate change on vulnerable populations. As with the Feed the Future aquaculture program in Cambodia, the proposed project will advance aquaculture techniques and technologies for rural Cambodian households and address the impact of climate change on vulnerable populations. The proposed project will align with work undertaken by the Integrated Pest Management (IPM) CRSP. The project investigators have been in contact with project investigators of the IPM CRSP at Clemson University who have been working in Cambodia to increase farmer productivity by reducing losses from agricultural pests through integrated pest management. The planned collaboration would work to reduce the use of pesticides, thus their run-off into aquaculture ponds, streams and rivers through IPM strategies. Both Cambodia and Vietnam have a high dependency on fish and any adverse impacts to the fisheries and aquaculture sector in the region will have implications for food security, nutrition, poverty, livelihoods, economic development, and fish trade and markets. It is expected that the effects of climate change will have significant impact on Cambodian and Vietnamese capture fisheries and aquaculture. At the most fundamental level, climate change has the potential to impact on total fish production volumes available for food and trade, both domestically and to export markets. This proposed project will develop fisheries-specific adaptive measures which offer potential to maintain or increase food security, nutrition, and fisheries markets and trade. The proposed project will assess the impacts of climate change on fish value chains to determine impacts on markets and trade and to recommend adaptation strategies for markets for aquatic products from Cambodia and Vietnam. The proposed project is working to develop policy for the aquaculture of snakehead in Cambodia, which will provide aquatic products for human food consumption. The proposed project will also provide guidance to improve the processing activities for added value of cultured snakehead products, particularly for women, thus providing aquatic products for human food consumption.

Cambodia USAID mission has a focus on food security and agriculture (http://cambodiaharvest.org/). The Cambodia HARVEST project through USAID's Feed the Future program supports the Cambodian government's development strategy by increasing the country's agricultural productivity, improving the wellbeing of the rural poor, and promoting sustainable management of the country's rich natural resources. The overriding objective will be to support Cambodia's achievement of the Millennium Development Goals, including halving the proportion of people who suffer from hunger and reversing the loss of environmental resources. The Mission approach is to (1) Develop agricultural solutions to poor agricultural productivity, postharvest losses, food safety, lack of market access, environmental degradation and effects of climate change; and (2) Emphasize quick impacts and results. This proposed project supports this initiative through the introduction of sustainable aquaculture technologies, through demonstration on farmer ponds, through regular and continuous technical assistance, and through strengthening the value chains through improvements in processing, postharvest, and trade and market access.

Vietnam USAID mission does not work on agriculture but does work on climate change (http://www.usaid.gov/vietnam/global-climate-change). The Government of Vietnam has identified climate change as a priority area for development assistance due to Vietnam's extreme vulnerability to climate change impacts. USAID's climate change initiatives in Vietnam follow the framework provided in the Climate Change and Development Strategy, released in January 2012. USAID's Vietnam Forest and Deltas Program supports adoption of land use practices to address deforestation and degradation of forests and other landscapes and increase resilience of people, places and livelihoods in delta areas through assistance for adaptation and disaster risk management. This proposed project supports this initiative through its focus on understanding the impacts of climate change on nutrition, food security and trade and the use of aquaculture as an adaptation strategy in the Mekong Delta region.

LEAD US UNIVERSITY: PURDUE UNIVERSITY

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Project Title

AQUACULTURE DEVELOPMENT AND THE IMPACT ON FOOD SUPPLY, NUTRITION AND HEALTH IN GHANA AND TANZANIA

AquaFish Project Theme

IMPROVED HEALTH AND NUTRITION, FOOD QUALITY, AND FOOD SAFETY

Investigations

13HHI01PU	Assessing the Nutritional Impact of Aquaculture Policy in Fish Farming Districts in Tanzania and Ghana
13MER01PU	Development of a Cell-Phone Based Seafood Market Information System (SMIS) in Ghana: Application to Tilapia
13MER02PU	Value Chain Analysis of Farmed Nile Tilapia (Oreochromis Niloticus) and African Catfish (Clarias Gariepinus) in Tanzania
13QSD01PU	Spat Collection and Nursery Methods for Shellfish Culture by Women
13BMA01PU	Coastal Women's Shellfish Aquaculture Development Workshop
13IND01PU	Identifying Local Strains of Oreochromis Niloticus that are Adapted to Future Climate Conditions
13SFT01PU	Evaluation of Invertebrates as Protein Sources in Nile Tilapia (Oreochromis Niloticus) Diets
13SFT02PU	Enhancing the Nutritional Value of Tilapia for Human Health

US and Host Country Institutions

US	Purdue University
	Virginia Polytechnic Institute and State University
	University of Arkansas at Pine Bluff
	University of Hawaii at Hilo
Ghana	Kwame Nkrumah University of Science and Technology
	University for Development Studies, Nyankpala Campus
Tanzania	Sokoine University of Agriculture
	University of Dar es Salaam

Other Collaborations and Linkages

Western Indian Ocean Marine Sciences Association (WIOMSA)

Project Summary

This project aligns with USAID's FTF concept of sustainable intensification addressing issues related to protein-energy nutrition and diets; enhancing the productivity frontier; improvements in productivity and sustainability; and aquaculture policies. Focus on human nutrition and gender cuts cross the investigations in this project. The goal of FTF Tanzania, among other things, is to implement programs that will "achieve improved income and nutritional status from strategic policy engagement and institutional investments." Work in Tanzania under this project includes 3 studies and 1 activity. Investigation #1 studies how fish consumption and fish farming are linked to various nutrition-based indicators for food security. The study adopts anthropometrics framework as a means to measure human welfare in relation to food supply and other development processes. Results from this investigation will inform national strategic policies on animal protein supply, which will contribute to achieving improved income and nutritional outcomes of rural populations. A second investigation, #2 aligns with FTF's aim of "increasing trade in … target value chain by at least 25 percent through improved rural infrastructure and improved value chain efficiency." A better understanding of the relationship between aquaculture value chain development and food security is accomplished in Investigations #1 and #3. Both utilize the same household data collection process, and that linkage will provide some clarity on aquaculture value chain development and the contribution of aquaculture to improved nutritional status. In particular, Investigations #1 and #3 include geographic targeting to integrate nutritional issues and value chain development, especially where women play a major role in the aquaculture value chain at the processing and marketing stages.

Issues relating to women and young children in Tanzania are addressed in Investigations #4 and #5. Women are important when it comes to instituting behavior change for improved nutrition because of their roles in household food production and supply. Women have become leaders in coastal aquaculture in Zanzibar, including seaweed and shellfish farming development activities for some time now. AquaFish has had an eight-year collaborative effort with the Institute of Marine Sciences (IMS) and the Western Indian Ocean Marine Science Association (WIOMSA) in research and extension activities to the women involved in shellfish farming. Investigations #4 and #5 build on the previous work by AquaFish CRSP, IMS and WIOMSA by encouraging scaling up, increasing productivity, broadening women participation, and increasing incomes of the women. The involvement of WIOMSA aligns with private sector partnerships and FTF's push to leverage private sector capacity to develop the various agricultural sectors in Tanzania. The Tanzania USAID mission has supported the shellfish farming efforts in the past directly and in partnership with the USAID SUCCESS program. They have also supported similar aquaculture efforts such as seaweed farming by women and milkfish farming development. Several of the current partners have also been active in these efforts. Food security and agricultural development are a high priority for the Tanzania mission. There is a high level of interest and great potential in the East Africa region to further develop both bivalve shellfish farming and fisheries management. This effort along with related efforts through USAID's SUCCESS program and through other international donor efforts provides a model for community-based development of livelihoods linked with conservation that directly and indirectly improves nutrition and food safety.

In Ghana, FTF aims to help "Significant numbers of additional rural populations … achieve improved income and nutritional status from strategic policy engagement and institutional investments." Few studies have documented fatty acid intake and status in developing countries, but available data indicate that many people have an inadequate intake of fats, and a suboptimal intake of n-3 essential fatty acids (EFAs) in particular. The n-3 and n-6 fatty acids are both essential for human health and must be acquired from the diet. Efforts to capture the impact of interventions on human health particularly women and children are also addressed in studies pertaining to Ghana. Investigation #8, addresses the need for enhancing the nutritional value of farmed species, the outcome of which will have a long-term impact on the food system and on human health. The study is about a practical diet development for Nile tilapia in Ghana that will result in production of a fish with a healthier lipid profile (enriched in n-3 fatty acids) compared to conventionally grown fish.

Efficient information flow is crucial to a successful aquaculture business model. Therefore, FTF Ghana also focuses on "high impact value chain activities," which aligns with the objectives for Investigation #2. This investigation develops a Market Information System (MIS) for Nile Tilapia in Ghana based on an electronic platform for mobile phones. This is very useful and will contribute to reduced post-harvest losses, risk management strategies, and reduced marketing costs, thereby increasing the availability of fish. Investigation #6 takes a longer-term view of identifying local species of tilapia that may have a role to play in mitigation strategies of climate change impacts in future. Knowledge of climate adapted tilapia species identified under this investigation addresses diversification and help mitigate some of the diverse effects of climate change on aquaculture. The lead institution, Purdue University has been involved with five USAID CRSPs, i.e., Integrated Pest Management (IPM), Sorghum, Millet and Other Grains (INTSORMIL), Aquaculture and Fisheries (AquaFish), Peanut, Sustainable Agriculture and Natural Resource Management (SANREM), and Global Nutrition (NCRSP) working in several West and East African countries. Discussions have already taken place between PIs involved in AquaFish and NCRSP at Purdue on collaborations involving the nutrition research in Uganda, Malawi and Tanzania. The student who will work on Investigation #1 will be co-supervised by PIs involved in AquaFish and NCRSP at Purdue University. Sokoine University of Agriculture (SUA) in Tanzania, our partner institution, currently hosts the Innovative Agriculture Research Initiative (iAGRI), an FTF project in Tanzania aimed at increasing food security and building capacity. Kwame Nkrumah University of Science and Technology (KNUST) in Ghana is also a collaborating institution in USAID's FTF Africa Research in Sustainable Intensification for the Next generation (Africa RISING) project in Ghana. Collaborative opportunities therefore exist for AquaFish with other FTF programs in Ghana and Tanzania.

LEAD US UNIVERSITY: UNIVERSITY OF MICHIGAN

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Project Title

DEVELOPMENT OF MORE EFFICIENT AND ENVIRONMENTALLY SUSTAINABLE AQUACULTURE SYSTEMS FOR NEPAL

AquaFish Project Theme

ENVIRONMENTAL MANAGEMENT FOR SUSTAINABLE AQUATIC RESOURCE USE

Investigations

13QSD02UM	Reproduction and Seed Production of Sahar (*Tor putitora*) in Chitwan, Nepal
13SFT08UM	Production of Periphyton to Enhance Yield in Polyculture Ponds with Carps and Small Indigenous Species
13MER06UM	Household Fish Ponds in Nepal: Their Impact on Fish Consumption and Health of Women and Children; and their Constraints Determined by Value Chain Analysis; and their Extension Through School Ponds and Women's Fish Farming Groups
13IND04UM	Two Small Indigenous Species to Improve Sustainability in Typical Polyculture Systems in Nepal
13BMA06UM	Demonstrating the Value of Tilapia and Sahar Production in Polyculture Ponds Using Government Farm and On-Farm Trials
13HHI04UM*	Establishing School Ponds for Fish Farming and Education to Improve Health and Nutrition of Women and Children in Rural Nepal

* *Investigation conditionally accepted. The PI will submit a work plan change and IRB approval (or waiver) before work gets started on this investigation.*

US and Host Country Institutions

USA	University of Michigan
Nepal	Agriculture and Forestry University

Other Collaborations and Linkages

Fisheries Research Center, Nepal Agricultural Research Council
Directorate of Fisheries Development

Project Summary

Nepal is a poor country; most residents are at best educated at the level of primary schooling, and many are undernourished or even malnourished (Bhujel et al. 2008). As a result of this poverty, most planning documents produced by the government, as well as outside organizations, concentrate on human health and nutrition as the main focus for future development of aquaculture. This focus is long standing. In 1976, Rana and Rajbanshi developed a National Plan for Development of Aquaculture in Nepal, which focused on increasing production of household ponds and other systems that would provide nutrition to poor households as the main concept. Subsequent plans in Nepal, including the Fisheries Perspective Plan (GoN

2000), the Strategic Vision of Aquaculture Research (NARC 2010), and evaluations by FAO (2013) all maintain nutrition for poor families as the main focus.

Throughout the poorer countries of Asia, small indigenous species of fish (SIS) are promoted as a means to provide health benefits for poor consumers. The benefits of their consumption include increased intake of calcium and vitamins (such as vitamin A) because the fish are generally consumed whole. In addition, these fish, when cultured or captured, are generally consumed in the home rather than sent to market, so they provide direct nutrition. While SIS can be caught from natural waters, they have not been well incorporated into aquaculture production systems. For example, the polyculture systems, which are the mainstay of commercial aquaculture in Nepal, largely use 5-7 carp species, all targeted on large carp species sold to market. While SIS could be incorporated into these polyculture systems possibly without any loss of yield for the large carp species [2] this has seldom been done, and there is no research basis to indicate whether such incorporation would be helpful or damaging to overall production. Over the first two years of this grant, our project will focus on this incorporation of SIS into polyculture systems to determine if it is a viable means to increase food production for poorer households.

A third area of focus for our proposed research is the enhanced production of native species, particularly sahar, a cool water species indigenous to Nepal. Again, all of the aquaculture planning documents described above had a focus on fish production in colder regions of the country. While these plans generally called for trout culture, we have maintained that sahar may be a more successful alternative because it is a native species, valued by local inhabitants, and important as a target of restoration. We have proposed studies to incorporate sahar in on-farm trials, as well as to expand sahar seed production to other regions of the country. While we may begin to evaluate the expansion of trout culture in the country over our five-year program, this is not our current goal. There is a nascent trout production near Pokhara, and we will evaluate its potential and role in the future. In addition to sahar, we propose work to establish aquaculture systems for another indigenous species, the stinging catfish. This is early development work, as culture of this species is in infancy, and our project to produce a demonstration farm and have some on-farm trials is the first in a series to promote this species. Over the five-year life of this project, we intend to conduct further, more directed research on constraints of catfish production, based on the outcome of our demonstration trials.

The Feed the Future (FTF) program "addresses undernutrition in women and children, by increasing the availability and access to nutrient dense foods through research on horticulture crops, livestock, fish and dairy, food safety threats, such as mycotoxins and other contaminants, and on household nutrition and food utilization" (R. Bertram 12/07/12). Of relevance to aquaculture and this proposal is the focus on small-scale farming and methods meant mainly to enhance household consumption of fish rather than sale to market. While both local consumption and market sales can enhance family nutrition, use of household ponds and their products is more direct and controllable. For example, Bhujel et al. (2008) demonstrated that women in Nepal from low-income households tend and manage farms, while the men often leave the household to secure employment elsewhere. So fish products from household ponds will be available for women to use directly in the household and should therefore directly improve nutrition.

A second component of this FTF goal is to increase the supply of livestock, including fish, to prevent undernutrition in children. This is particularly important for small-holder farmers who face the challenge of growing a crop to sell and produce some income with the constraint of eating some of the crop to improve household nutrition, but at the same time, this consumption reduces profit. Inclusion of SIS into aquaculture systems alleviates this strain, as it most likely will produce fish for household consumption while not diminishing the productive capacity of the ponds for growing the marketable crop. In fact, the addition of periphyton-based aquaculture into these ponds should also enhance overall production and increase production of marketable fish as well as SIS.

Our proposal is submitted under the AquaFish theme of Environmental Management for Sustainable Aquatic Resources Use. This theme focuses on producing more sustainable aquaculture systems through environmental management, in both the production system and in managing the wastes from aquaculture. Our research program will address this theme by using low-intensity and more sustainable system manipulations to produce crops without requiring effluent discharge or use of energy. While feeds are used in the polyculture systems for carp, they are mainly waste agriculture products and therefore are integrated from the agriculture system. Thus, all of the aquaculture systems studied or extended in this proposal focus on managing aquaculture for minimal environmental impacts as well as for efficient fish production.

Overall, the AquaFish Innovation Lab has four themes, and this proposal focuses mainly on the first three of these themes. The work described above clearly focuses on the Improved Health and Nutrition, Food Quality, and Food Safety theme, as well as Income Generation for Small-Scale Fish Farmers. None of our current projects are focused on Enhanced Trade and Investment for Global Fishery Markets, and indeed, little of Nepalese aquaculture at present has a target of export sales, but rather is planned to reduce dependence on foreign imports, mainly from India.

Among the seven areas of concern for the USAID mission in Nepal, Agriculture and Food Security is the first and foremost. About 70% of the workforce in Nepal relies on agriculture for their employment, yet only 38% of the country's GDP is from agriculture. Nepal struggles to produce enough food for its people, and low nutritional status is a major issue in the country. One of the targets of the USAID mission is to help small-holder farms in conflict-stricken and flood-prone areas improve their production and standard of living. The work we propose on household ponds and small-scale aquaculture fits well within this development context.

LEAD US UNIVERSITY: AUBURN UNIVERSITY

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Project Title

AQUACULTURE DEVELOPMENT IN KENYA AND UGANDA: ADVANCING COST-EFFECTIVE TECHNOLOGY, MARKET ASSESSMENT, AND END-USER ENGAGEMENT

AquaFish Project Theme

ENVIRONMENTAL MANAGEMENT FOR SUSTAINABLE AQUATIC RESOURCE USE INCOME GENERATION FOR SMALL-SCALE FISH FARMS

Investigations

13IND03AU	Development of Low-Cost Captive Breeding and Hatching Technologies and Management Practices for Two African Lungfish Species (*Protopterus aethiopicus* and *P. amphibius*) to Improve Livelihoods, Nutrition, and Income for Vulnerable Communities in Uganda
13BMA04AU	New Approaches to Inform, Motivate, and Advance Small and Medium-scale Fish Farmers: Building Industry Capacity Through Cell Phone Networks, Training, and Market Participation
13MER05AU	Assessment of Market Opportunities for Small-Scale Fishers and Farmers in Central Uganda
13SFT06AU	Assesment of Growth Performance of Monosex Nile Tilapia (*Oreochromis niloticus*) in Cages Using Low Cost, Locally Produced Supplemental Feeds and Training Fish Farmers on Best Management Practices in Kenya
13SFT07AU	Formulation and Manufacture of Practical Feeds for Western Kenya
13BMA05AU	Development of Low-Cost Aquaponic Systems for Kenya

US and Host Country Institutions

USA	Auburn University
	University of Arizona
	Alabama AandM University
Kenya	University of Eldoret
	Uganda Makerre University

Other Collaborations and Linkages

Ministry of Fisheries Development
National Fisheries Resources Research Institute

Project Summary

The AFIL project follows the simple premise that fish are high in omega-3 and other fatty acids that are vital for human development, particularly for cognitive abilities in children. We focus on increasing the supply of fish, particularly in areas away from normally abundant supplies from Lake Victoria and other large water bodies. Our focus on peri-urban and rural production aims to increase the supply of fish protein in the environs of the poorest Ugandans and Kenyans. Further, our focus on small and medium scale operations is intended to improve the intra-household supply of quality protein in poor families.

The Nutrition Innovation Lab is working in Uganda, among other locales. Their baselines survey will examine the relationship between key agricultural, livelihood, food security, nutritional, health, and gender outcomes in vulnerable households and populations. The results of this study may elucidate how fresh fish, dried fish, and fishmeal augment diets in these populations, particularly identifying seasonal deficits that might suggest production and value chain strategies that would improve nutritional security. Each of the studies resonates with Theme "B," Income Generation for Small-Scale Fish Farmers. The study that addresses the development of low-cost captive breeding and hatching technologies for the African Lungfish (*Protopterus spp*) is intended to improve livelihoods, nutrition and income for vulnerable communities in Uganda. The new species could provide an expanded availability of now-rare food item for local markets by allowing small producers to culture a vigorous fish tolerant of a wide range of water quality conditions. The activity that explores new approaches to inform, motivate, and advance small and medium-scale fish farmers addresses the often unrecognized fact that new technologies are not what constrain aquaculture in Africa. Rather is the lack of compliance with known protocols for reproducing and growing fish. One way to build industry networks that will reinforce production messages is through cell phone networks, training, and market participation through mobile devices, particularly for remotely located farm operators. The study that provides an assessment of market opportunities for small-scale fishers and farmers in Central Uganda will complement and extend the aforementioned study. It will clarify those strategies that work for successful producers and outline the structural barriers to improved market performance. Assessment of growth performance of monosex Nile tilapia (Oreochromis niloticus) using low cost supplemental feeds in cages and training fish farmers on best management practices in Kenya will provide practical guidance to the large number of new fish farmers in that country. Formulation and manufacture of practical feeds for Western Kenya will identify practical means for increasing the availability of well-formulated floating feeds that are important aspects of productive fish farming. Finally, the development of low–cost aquaponics systems for Kenya will provide opportunities for small operators with aquatic resources on their small land holdings. Requiring a higher skill level, aquaponic systems can be important local sources of food, nutrition, and incomes, as well as seed stock for surrounding farms.

USAID supports a number of current and forthcoming activities in Uganda. Community Connector (2016) endeavors to improve nutrition, achieve sustainable food security, and increase income by integrating vulnerable households into the market economy and connecting beneficiaries to other service providers. Clearly fish and fish products have a role to play in generating income and food security and the outputs from the AquaFish Innovation Lab will dovetail with the goals of this effort. The Livelihoods and Enterprises for Agricultural Development (LEAD) project is just ending as our work begins. This project provided training and demonstration in fish culture in Northern areas of Uganda. The interest and information disseminated by this project provides a foundation for new efforts to intensify and augment the practice of aquaculture. The new Agricultural Inputs Activity is intended to increase the use of improved seed, pest controls, and soil amendments by building the capacity of large-scale input suppliers and increasing marketing and education to farmers. Our project clearly would like to partner with this group to increase the supply and quality of aquaculture feeds available in the country. Public Sector Capacity Building Activity will strengthen the capacity of the Ugandan Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to implement the national Development Strategy and Investment Plan (DSIP) and to develop a cadre of future agriculture leaders. Training in aquaculture and other disciplines associated with our project by participating institutions could clearly help to advance this effort. The Therapeutic and Supplementary Products for Improved Nutrition (TASPIN) project will facilitate the sustainable local production and distribution of nutritious and therapeutic foods. We assert that fish, dried fish, and fishmeal are some of the most nutritious products that rural Uganda can provide growing urban and peri-urban families and children.

In Kenya, AFIL project's studies and activities complement the USAID value chain programs that contribute export of fish to neighboring countries in the East Africa region. Although fish traders capture much of the value, export income went to smallholder farmers who grow the animals. The project also complements farming and pastoral programs that focus on the entire value-chain: from seeds, soil and production methods to connections to markets. Improving these pathways and broadening the base of participation will keep more income in the village and improve the well-being of children and families. Where it is possible, AFIL works with the Kenyan government to enact and implement policies that ease the way for small-scale farmers and increase incomes for rural households that produce fish. Our training and demonstration activities endeavor to boosts the production skills, business acumen and income of small-scale farmers. Complementing USAID efforts, the project trains farmers in business as well as sustainable methods to produce higher yields of fish by adhering to know strategies for production, protection, and harvest. We seek to economically empower women by ensuring their participation in project activities, demonstrations, and training programs.

Our projects induce the attention and support of the host country institutions in manifold ways. The colleagues who work with us direct their teaching and outreach activities to augment the project objectives. Our collaborations with NGOs induce them to include aquaculture in their portfolio of activities. When our colleagues speak in a training event or support our efforts to reach farmers, the organization's resources broad sets of contacts and established mechanisms are leveraged to serve the objectives. In Kenya, the close collaboration with a senior minister in the Department of Fisheries is an especially valuable contact to leverage resources.

We plan to extend the successful Aquaculture Symposium and Trade Show model to other AFIL countries, particularly Ghana and Tanzania. It is important to develop private institutions led and managed by producers who can voice the concerns of their industry to elected officials and the private sector. We also expect to have several of our partners present project goals and results at international forums including World Aquaculture Meetings and the International Symposium on Tilapia in Aquaculture.

We seek to work with other public, private, and nonprofit organizations whenever we share interest in obtainable joint outcomes. We are currently coordinating with a Farmer-to-Farmer program in Kenya and hope to continue that relationship in the future.

PART II. RESEARCH PROJECT INVESTIGATIONS

TOPIC AREA

PRODUCTION SYSTEM DESIGN AND BEST MANAGEMENT ALTERNATIVES

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DEVELOPMENT OF LOW-COST AQUAPONIC SYSTEMS FOR KENYA

Production System Design and Best Management Alternatives/Experiment/13BMA05AU

Collaborating Institutions and Lead Investigators

University of Arizona (USA)	Kevin Fitzsimmons
Eldoret University (Kenya)	Julius Manyala
Kenya Ministry of Agriculture, Livestock and Fisheries	Charles Ngugi

Objectives

1. Design a small-scale aquaponic system for educational purposes and hobby production of fish and vegetables.
2. Design a moderate-scale aquaponic system for potential commercial application.
3. Construct a small-scale system and a moderate-scale system to develop proof of concept and training.
4. Assess the government funded Economic Stimulus Programme impacts on fish farming in terms of supply enhancement, rural poverty alleviation, and food security.

Significance

Aquaponic systems have become a primary tool for teaching agriculture and natural resources around the world (Graber and Junge, 2009; Rakocy, 2000). The systems have also become popular with small-scale hydroponic producers in many locations, enabling some small-scale fish farmers to generate substantial incomes for their households. In Kenya, the large number of small pond systems, often less than 200 meter square, are not proving capable of producing enough fish to be of financial interest to farmers. One option to increase fish productivity and at the same provide an additional revenue stream is to integrate the fish culture more directly with vegetable production. The rapid cash flow with vegetables, especially lettuce, basil, parsley, and bok choy, provide a more direct return for the farmer.
The Kenyan Government promote farming of fish for food, profit and employment, and to supplement the capture fisheries funded the Ministry of Fisheries Development under the Economic Stimulus Programme (ESP) that subsidized the distribution of fingerlings. Funding began in the financial year 2009/2010 and continued through to 2011/2012. This program focuses on increasing fish production throughout the country. Although focused more broadly than aquaponics, the ESP provides a unique opportunity and context for implementation of aquaponics and other novel production strategies.

Quantified Anticipated Benefits

We anticipate that the demonstration unit will be in a high visibility location and receive attention from faculty, staff, students, and local area farmers. We expect that at least 200 individuals will observe the workings of the unit. The fish and vegetables produced will be consumed by students or sold to generate funds for student activities. The unit will be instructive for farmers who have ponds and wish to use the nutrient enriched water to irrigate field and vegetable crops. We will document the increased levels of nitrogen that can contribute to fertilizing plants and reducing the costs for chemical fertilizers for farmers.

<u>**Experimental Design**</u>

Task 1. Design a small-scale aquaponic system for educational purposes and hobby production of fish and vegetables

A small-scale aquaponic system will be designed using ready available materials from the local area. The goal will be to design a physical system that is low cost, easy to replicate and will have the ability to maintain up to 50 kg of tilapia and irrigate and fertilize 250 heads of lettuce (approximately 100kg) or other plants. We will focus on minimal electrical demand and the potential to operate with a single solar panel. The design will be shared with a couple of outside experts (Rakocy, Ebling, and Timmons) for evaluations and comments.

Task 2. Design a moderate-scale aquaponic system for potential commercial application

We will utilize some basic design parameters from the University of the Virgin Islands (Rakocy et al. 2000; 2004) and the University of Arizona (Licamele 2009) to design an appropriate scale aquaponics system for farmers in Kenya. The goal will be to design a system that would utilize water from a pond to irrigate and fertilize up to 1000 square meters of vegetables. We will consider two models, one a hydroponic system with water returned to the fish, and the other a one way model with water going only to the vegetables with none being returned. The designs will be shared with a couple of outside experts (Rakocy, Ebling, and Timmons) for evaluations and comments.

Task 3. Construct the small-scale system to develop proof of concept and training purposes

On campus we will construct a model small-scale system based on the design that we have after input from outside colleagues. The operational system will be used to test the methods, the equipment, and subsequently train students and local farmers. Data on water quality, growth rate and yield of fish and plants, and energy demand will be collected. A simple enterprise budget will be prepared based on the capital costs, operational costs and revenue sales that would be generated from such a system.

Task 4. Construct a moderate-scale system

We will construct a system at the demonstration fish farm across the road from the main Eldoret Campus. Data on water quality, growth rate and yield of fish and plants, and energy demand will be collected for the moderate scale system. An enterprise budget will be prepared based on the capital costs, operational costs and revenue sales that would be generated from the moderate-scale system. The operation will be utilized for training staff and students as the interest level in these systems continues to expand.

Task 5. Assess the broader impacts of the fingerling distribution program

This activity will measure outcomes of Economic Stimulus Programme (ESP) in terms of its impacts on aquaculture development, rural economic growth, poverty alleviation and food security. The assessment will use administrative records and field observations to estimate the nature and kind of benefits the effort has had on supply, household incomes, and rural development in Kenya. Results from the impact analysis of rural aquaculture development will also be useful to private investors for making sound investment decisions especially in areas of seed and feed production.

<u>**Impact Assessment**</u>

Several current fish farmers have expressed interest in aquaponics as a method to increase farm productivity. There is growing demand for food from organic farms across Kenya, especially from the tourist trade vendors and from the general public concerned with the misuse of chemical fertilizers. An aquaponic growing system could help meet this demand and present a business opportunity for capable growers. Commercial flower growers have also expressed interest in aquaponics to make better use of their greenhouse facilities and to diversify their product stream. Teachers are also likely to take the idea of integrated farming as a valuable teaching tool. At the end of the project, we will conduct a survey following up with the farmers who have expressed interest in the farming system to determine how many have adopted some of these practices or otherwise altered their production methods using aquaponics.

Schedule

July 2013	Begin design of small-scale system
August 2013	Begin design of moderate-scale system
September 2013	Send designs for outside reviews and comments
October 2012	Begin construction of small-scale system
November 2013	Begin collection of trial data
December 2013	Begin construction of small-scale system
January 2014	Collect data from each system.
February 2014	Continue data collection from each trial
April 2014	Harvest systems and determine growth and yield
May 2014	Compile results and analyses of both systems.
June 2014	Prepare and submit final reports

Deliverables

ITEM	MECHANISM (E.G. PODCAST REPORTS FACTSHEETS ETC.).
Description of systems	Leaflet for farmers
Results of trials	Applied report
Growth and yield results	Journal article
Comparative perspective on production strategies, feed, and seed supply	Joint seminar with ILRI collaborators on African aquaculture production systems

PRODUCTION OF NUTRIENT-RICH SMALL FISH *MOLA* AND FRESHWATER PRAWN USING INTEGRATED CAGE-POND/CARP POLYCULTURE FOR NORTHWEST BANGLADESH

Production System Design and Best Management Alternatives/Experiment/13BMA03NC

Collaborating Institutions and Lead Investigators

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Objectives

This investigation complements Investigation 5, extending integrative carp/ *Mola*/ prawn culture to regions of Northwest Bangladesh (Bogra district). Unlike the Southwest, carp ponds in Northern Bangladesh are generally too deep for prawn culture. This impoverished region currently lacks crop diversification, and could substantially benefit from incorporating both high-value (prawns) and highly nutritious (*Mola*) aqua-foods into traditional carp farming. This investigation will address these problems through a novel "cage/pond" polyculture technology. The specific objectives of this study are to:

1. Determine the stocking densities for *Mola* and prawns for integrated cage/pond aquaculture with major Indian carps.
2. Identify the performance of this integrated system in terms of production yields for all species, market returns, and effects on environmental water quality.
3. Assess the benefits of the proposed design on the nutritional and economic well being of rural farming families through household surveys. The nutritional assessment will specifically target women and children of the households.

Significance

Fish are the greatest source of animal protein available to most rural Bangladeshis (Belton et al., 2011). As aquaculture currently contributes 53% of the total finfish produced (3.56 mmt: DOF, 2013), the development of technologies to enhance production capacity and income earnings, while reducing environmental footprint, is key to improving the lives of rural families. Despite improvements in production for some species (*e.g. Pangasius*, tilapia), the dominant fish raised and consumed by rural households are the Indian carps (Rohu, *Labeo rohita*; Catla, *Catla catla*; and Mrigal, *Cirrhinus cirrhosus*). Raised almost exclusively by low-income households in small homestead ponds, production of other seafoods can significantly improve the dietary nutrition and economic outlook of the rural poor, as well as better utilize available pond resources associated with carp farming. As carps are typically unresponsive to supplemental feed inputs since they primarily consume natural plankton, intensive production of Indian carps has not been profitable in most cases. The focus of this investigation is to improve the production yields, dietary nutrition, and economic profitability of small-scale carp farmers in Northwest Bangladesh through integrative polyculture, where key additional crops (*Mola*, prawns) are added.

Efforts are currently underway to promote the cultivation of small, indigenous species (SIS) that are particularly high in minerals or micronutrients (Wahab *et al*. 2003, 2008, 2011). Cultivation of these species address several problems currently associated with aquaculture intensification in Bangladesh, including being well-adapted to local climes and weather fluctuations, limiting the reduction of natural biodiversity, and reducing dietary deficiencies associated with consuming fish of more limited nutritional value. One promising SIS is the *Mola* fish (*Amblypharyngodon mola*), which is particularly rich in both vitamin-A (~1900 IU, Thilsted *et al*. 1996) and minerals (e.g. calcium, zinc, iron). The research team at BAU (Dr. Abdul Wahab, HC Lead PI) has worked for the last decade to develop and domesticate *Mola* for culture with Indian carps. Although now understood to be significantly beneficial to nutrition (Roos *et al*. 2007), the current production levels for *Mola* are relatively low (1-2/m^2). As *Mola* are sought after in local markets for its perceived health benefits, the economic conditions governing its production appear to be changing. Thus, it necessary to develop technologies for greater cultivation of this species, including availability and transportability of seed stock, development of mass production designs and stocking density, and further development of both rural and urban markets. By coupling *Mola* production to that of Indian carps, augmented with high-value prawns, this investigation seeks to promote greater dietary nutrition in the household along with higher earned incomes.

Integration of high-value species in the polyculture of Indian carps and *Mola* is key to increasing both on-farm productivity and economic viability for these endeavors. The freshwater prawn (*Macrobrachium rosenbergii*) is a high-value export commodity traditionally cultured in the modified rice fields (ghers) of Southern Bangladesh (Wahab et al., 2012). Introduction of this crop to other regions of Bangladesh (e.g., North) has not been successful, as the carp ponds in other regions are too deep for prawn culture, and significant predation occurs when the prawns congregate near the edges of the pond (Enamul Hoq, BFRI, pers. comm. 2012). This investigation will employ a novel method of cage prawn culture, which is a new concept in Bangladesh, but has been proven successful in the Philippines (Cuvin-Aralar *et al.* 2007). Preliminary investigations of prawn culture with *Mola* (Kunda *et al*. 2008) are promising, and studies are currently being proposed to integrate prawn/carp/*Mola* polyculture into the ghers of Southwest Bangladesh (Inv. 5). This investigation complements those studies by evaluating the feasibility of cage-prawn culture, in the deeper ponds of North Bangladesh, with both *Mola* and Indian carps. As prawn cage culture is a new methodology, this investigation will determine the prawn stocking density appropriate for this design and examine its potential economic profitability.

This investigation will test multiple stocking densities for both *Mola* and prawns into traditional farming of Indian carps. Previously established AquaFish CRSP fertilization regimes (28 kg N/ 7 kg P) will be utilized (Egna and Boyd, 1997), with only prawns receiving additional feed inputs. These studies will be tested on-farm using ponds donated by 30 participating households in the Bogra district (Nandigram Upazila) of Northwest Bangladesh, who will receive direct training on the benefits and/or effectiveness of this design. We hypothesize this will be of substantial benefit to rural farmers, and can serve as a working model for dissemination of this technology to other regions. Greater production yields of *Mola*, consumed directly or sold in local markets, should significantly improve the dietary nutrition of rural families (particularly for women and small children) where Vitamin-A and iron deficiencies are commonplace (Micronutrient Initiative/UNICEF, 2004; West, 2002). Further, significant improvements in economic earnings and profitability can be made through co-production with high-value prawns (cash crop).

Quantified Anticipated Benefits

1. Availability of nutrient rich *Mola* fish will directly benefit human nutrition, particularly for women and small children of rural farming households.
2. Excess production of *Mola* and Indian carps (above family dietary needs) can increase earned income through sale of these crops in local bazaars and markets.
3. Efficient usage of all feeding niches in the ponds may result in higher production yields of both Mola and carps, while leading to better utilization of aquatic resources with improvements to or no additional negative impact on environmental water quality.
4. Cage prawn aquaculture methods will be introduced for the first time in Bangladesh, which could then be implemented in other regions where gher/prawn farming techniques cannot be used.
5. The sale proceeds from high-value prawns will significantly improve earned incomes of rural farmers in Northwest Bangladesh, a region where only carp farming is traditionally practiced.

The Southeastern U.S., including the State of North Carolina has a growing prawn industry that complements the pond aquaculture of various warm water finfish. A demonstration of the efficacy and appropriate stocking densities used in prawn cage culture could provide farmers the flexibility of integrating this high-value crop into culture with other finfishes. Polyculture development could enhance water resource use and broaden the diversity of crops grown by U.S. aquaculture farms.

Plan of Work

Location

This investigation consists of three studies, which will be carried out on participating farms located within the Bogra district (Nandigram Upazila) of Northwest Bangladesh. Water quality, economic return, and soil nutrient analyses will be performed at BAU, Mymensingh, Bangladesh.

Methods

1. Evaluation of different stocking density for *Mola*, with prawns and Indian carps, and its effect on production yield, market return, and environmental water quality.

This on-farm study will establish if *Mola* fish (*A. mola*) production can be increased with the pond culture of major Indian carps (Rohu, *L. rohita*; Catla, *C. catla*; Mrigal, *C. cirrhosus*) and cage culture of prawns (*M. rosenbergii*). In the Northwest, several Indian carps are traditionally cultured together in equal densities as each occupies a discrete feeding niche (*e.g.* surface, column, and bottom feeders; (Jhigran, 1975; Milstein et al., 2008). Alternate densities of Indian carps will not be evaluated as the current design represents a traditional and effective practice that has long been standardized. The following experimental design is proposed:

Parameter/ Stocking Density	Treatment 1	Treatment 2	Treatment 3
Prawns (*M. rosenbergii*)	$15/m^2$	$15/m^2$	$15/m^2$
Mola (*A. mola*)	$2.5/m^2$	$5.0/m^2$	$10.0/m^2$
Rohu (*L. rohita*)	$0.33/m^2$	$0.33/m^2$	$0.33/m^2$
Catla (*C. catla*)	$0.33/m^2$	$0.33/m^2$	$0.33/m^2$
Mrigal (*C. mrigala*)	$0.34/m^2$	$0.33/m^2$	$0.34/m^2$
Replicate ponds (*n*)	5	5	5

In this design, the stocking densities of prawn and Indian carps will be held constant while *Mola* is tested at 3 stocking levels to see if production can be enhanced. Juvenile prawns (0.4 g) will be stocked in experimental 15 m^3 cages (L × W × H: 5 m× 3 m× 1 m; nylon netting) in all ponds (800 m^2 area, 1.5 m depth). The stocking density of prawns is based upon previously published work in the Philippines (Cuvin-Aralar et al. 2007). The prawns will be placed in 1 cage per pond, located 1-m away from the pond embankment. Ponds (N=15) will be provided by local villagers (Nandigram Upazila) and will be limed and fertilized prior to filling with water and stocking in accordance with local farming practices. Commercial feed inputs (30% CP) will be used only for prawn at 5% body weight throughout the study. Fertilization (28 kg/ha N; 7 kg/ha P; per week) will be applied during the entire production phase (5 months). Water quality will be monitored weekly on-site for temperature, dissolved O_2, pH, turbidity/transparency (secchi-disk). Additional water quality parameters (e.g. ammonia, nitrite, nitrate, phosphate, total nitrogen and total phosphate) will be collected every 2 weeks and measured at the Water Quality and Pond Dynamics Laboratory, BAU, Mymensingh. During the grow-out period, performance metrics (weights/lengths) for all species will be collected by monthly sub-sampling, followed by a total yield assessment at the end of study. Following self-recruitment (~ 60-90 days) partial harvesting of *Mola* will be carried out periodically (these yield recorded for final analysis) to allow for household consumption and population control (of *Mola*). Significant differences ($p < 0.05$) in water quality, total production yields (biomass), and prawn and carp production yields/growth will be determined and analyzed by One-way Analysis of Variance using SPSS software.

Null Hypothesis 1: There is no difference in production yields for Indian carps (Rohu, Catla, Mrigal) and prawns when Mola are stocked at different densities.

Null Hypothesis 2: There is no difference in environmental water quality when Mola are stocked at *different densities with both prawn and Indian carps.*

2. Evaluation of different prawn stocking densities, in cultivation with *Mola* and Indian carps, and its effect on production yield, market return, and environmental water quality.
This study will determine appropriate cage stocking density for prawns in polyculture with Mola and Indian carps, seeking to maximize economic returns for a high-value export crop without reductions in environmental water quality. Based upon the outcomes of Study 1 (best *Mola* stocking density), this study will then test different stocking levels of freshwater prawns (*M. rosenbergii*). The following design is proposed:

Parameter/Stocking Density	Treatment 1	Treatment 2	Treatment 3
Prawns (*M. rosenbergii*)	$15/m^2$	$30/m^2$	$45/m^2$
Mola (*A. mola*)	Best of Study 1	Best of Study 1	Best of Study 1
Rohu (*L. rohita*)	$0.33/m^2$	$0.33/m^2$	$0.33/m^2$
Catla (*C. catla*)	$0.33/m^2$	$0.33/m^2$	$0.33/m^2$
Mrigal (*C. mrigala*)	$0.34/m^2$	$0.34/m^2$	$0.34/m^2$
Replicate ponds (*n*)	5	5	5

Ponds (N=15) will be limed and fertilized before stocking in accordance with current practices for Indian carps (see Study 1). Special consideration will be taken to determine that over or under-fertilization of these ponds does not occur. As in Study 1, feed inputs will only be used for prawn culture (5% BW/day), with both *Mola* and carps utilizing primary production. Water quality and growth performance metrics will be collected as stated in Study 1. Analysis of Variance (SPSS) will be used to test significant effects ($p < 0.05$ on growth performance, water quality parameters, and total production yield (kg, all species).
Null Hypothesis 1: There is no difference in production yields for Indian carps (Rohu, Catla, Mrigal) and Mola when prawns are stocked at different densities.
Null Hypothesis 2: There is no difference in environmental water quality when prawns are stocked at different densities with both Mola and Indian carps.

3. Determine the perceived nutritional and economic benefits of the integrated cage/pond cultivation of Indian carps, *Mola*, and prawns through surveys of the on-farm study participants.
This study will evaluate participating families of the on-farm trials of Studies 1-2 (30 households) on the perceived nutritional and economic benefits of the proposed integrated farming design. These surveys will be balanced with the addition of 30 non-participating households utilizing traditional carp farming practices (no *Mola* or prawns) but have equivalent land holdings and economic status. The nutritional analysis will be performed by preset questionnaire developed by our human nutritionist collaborator (A. Rahim, HC Co-PI, University of Dhaka) and will specifically target the health and nutritional needs of women and small children within the household. As the families harvest *Mola* periodically, once they self-recruit within ponds in Studies 1-2, additional survey questions will target the frequency of fish consumption, methods of cooking, and distribution among the households. A separate questionnaire will also be given to assess perceived economic benefits of the prawn and *Mola* culture (administered by Dr. Sadika Haque, HC Co-PI, BAU). This survey will be analyzed in conjunction with the production yields (kg), feed costs, and estimated market returns (cost benefit analyses) collected from Studies 1-2. The findings of the research, should they prove beneficial, will be conveyed through production of a factsheet and shared directly with extension fisheries officers and local members of the WorldFish Feed the Future project for consideration of potential upscaling in the future.

Schedule
May 2014 – Sept 2014: Completion of Study 1
April 2015 – Aug 2015: Completion of Study 2
April 2014 – Sept 2015: Study 3; Final Technical Report

Deliverables
1. Introducing High-Value and Nutritious Crops – Studies 1-2 will report the total production yields for *Mola*, carps, and prawns (kg), the latter being new to this region. We anticipate successful cultivation of these crops together in Northwest Bangladesh using the integrated cage/pond design.
2. Improvements in Economic Profitability – The estimated market returns for carp, *Mola*, and prawns will be reported for Studies 1-2 along with overhead costs (fertilizer, feeds, post-larval prawns). We anticipate significant improvements in earned income from prawn farming (high market value). Perceived economic benefits will also be evaluated through cost-benefit analyses and questionnaires given to 30 participating farming families (Study 3). These surveys will be overseen by Co-PI (agricultural economist) within the HC.
3. Improvements in Human Nutrition – Perceived nutritional benefits to farming households will be evaluated through questionnaires given to participating families (Study 3), to be overseen by a senior human nutritionist (A. Rahim, HC Co-PI). We anticipate increased dietary consumption of Vitamin A and other micronutrients in women and small children through household consumption of *Mola*.
4. Documentation and Dissemination – The findings from these studies will be reported through the Technical Reports of the AquaFish Innovation Lab, and peer-reviewed literature (1-2 manuscripts). Thirty farming households will participate in on-farm trials and will also receive direct training on the effectiveness of cage/pond polyculture of *Mola* and prawns with Indian carps as well as the nutritional benefits of *Mola*.

THE CULTURE POTENTIAL OF *PANGASIUS* CATFISH IN BRACKISH (HYPOSALINE) WATERS OF THE GREATER BARISHAL REGIONS IN SOUTHERN BANGLADESH

Production System Design and Best Management Alternatives/Experiment/13BMA02NC

Collaborating Institutions and Lead Investigators

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Objectives

1. Evaluate whether the culture of freshwater *Pangasius* catfish can be successfully cultured in seawater- encroached hyposaline waters of coastal Southern region of Bangladesh.
2. Cultivation of indigenous mullet species with *Pangasius* in brackish water pond polyculture for greater production yields and nutrient efficiency.
3. Evaluate potential economic impacts for integrated *Pangasius*/mullet polyculture.

Significance

In Bangladesh, *Pangasius* catfish is considered as one of the most successful aquaculture species due to its relative ease in culture, high-market demand, and suitability to local climate conditions (Rahman *et al.,* 2005; Rahman, *et al*. 2012; Sarker, 2000). The focus of this investigation is to assess the potential for expanding the culture of *Pangasius* to Southern regions containing significant amounts of brackish (hyposaline) waters, the areas that are severely impacted by overfishing and global climate change (*e.g*., seawater encroachment, storms) and are currently underutilized for fish production. Production of *Pangasius* could theoretically ease poverty reductions for millions of low-income people in Southern Bangladesh by creating better employment opportunities through development of activities with backward and forward linkages to the market chain. Additionally, we will assess if indigenous mullet species (striped and goldspot mullet) can be incorporated into *Pangasius* culture to achieve better production yields (therefore better income earnings), potential improvements in environmental water quality through more efficient nutrient utilization, and improving nutrition through greater diversification of food resources in the coastal regions (greater Barishal District).

The river catfish (*Pangasius hypopthalamus*) was introduced to Bangladesh in 1990's, and since then it has become a thriving aquaculture industry with over 300,000 tonnes produced annually (Ali, *et al*. 2011; Edward and Hossain, 2010; Munir, 2009). Currently, much of the *Pangasius* production comes from the North and Central regions of Bangladesh (*e.g*., greater Mymensingh). In these regions, *Pangasius* are cultured both intensively with commercial feeds, semi-intensively (with limited feed), and in extensive (no feed) polyculture with both tilapia and carp (Ahmed, *et al*. 2010). High disease resistance, along with high stocking density with greater production rates (up to 120 fish /m^2, average 40 tonnes / ha; UNFAO, 2010), make *Pangasius* an ideal cultivar for increasing aquaculture production in Bangladesh, particularly in regions unfamiliar with farming this species, as well as reducing the burden of population growth. The greater Barishal district is one such region, which has traditionally relied on fishing or aquaculture of marine species (*e.g*., shrimp) for their economic livelihoods. Through over-fishing and the increasing frequency of natural calamities like cyclones (*e.g.* Sidr, Aila), this region is nearing depletion of wild fish stocks and currently over half a million fishermen have been suffering from severe poverty. Introducing *Pangasius* aquaculture to these coastal communities, whose water resources are largely underutilized, may significantly enhance the dietary consumption of protein for low-income families, as well as provide new sources of income and employment in an area.

Some studies suggest *Pangasius sp.* may be tolerant of salinity (David, 1962). Recently, juveniles of *Pangasius* catfish are reported to tolerate salinities up to 13 ppt without significant mortality (Castaneda *et al.,* 2010). Before significant resources can be allocated for promoting this industry in coastal regions, the growth performance of *Pangasius* in hyposaline waters must first be evaluated. Through increasing tidal (seawater) encroachment and storms, nearly 40 percent of the farmable water bodies in the greater Barishal district are now hyposaline (0.5 to 7.5 ppt), and this percentage is expected to increase in future years. This has significantly impacted culture of traditional freshwater species in the area. If *Pangasius* culture can be achieved in greater Barishal and other coastal regions, the production levels of this fish could effectively double (600,000 metric tones), thus may significantly impact the diet and economic viability of coastal communities. As similar problems exist for the lower Mekong Delta in Vietnam (Halls and Johns, 2013), a better understanding of growth performance and salinity tolerance can benefit aquaculture production throughout South-East and Central Asia. This investigation will focus on the salinity ranges endemic to coastal in-land regions of Southern Bangladesh (0-8 ppt) to assess the economic feasibility of *Pangasius* culture in these locales.

A key component for increasing production yields of *Pangasius*, without negative environmental impacts, is the incorporation of other trophic-level species for better nutrient utilization. We will evaluate whether two mullets, the striped mullet (*M. cephalus*) or the goldspot mullet (*L. parsia*), can be cultured with *Pangasius* in coastal regions of Barishal. As mullet is popular in local markets, farming of these fishes will augment the dietary needs and economic earnings of coastal households, while promoting better management practices for future *Pangasius* farming. The results from these studies will be presented at the AquaFish Innovative Lab Project Workshop and Farmers' Day.

Quantified Anticipated Benefits

1. We anticipate that culture of *Pangasius* catfish in hyposaline, brackish waters will yield similar production and economic returns as fish farmed in freshwater.
2. Culture of *Pangasius* catfish in brackish-waters of Southern Bangladesh has the potential to enhance annual aquaculture production to 600,000 metric tonnes.
3. We anticipate that successful development of this project will increase livelihood options and better food-security for low-income families impacted by overfishing and rises in sea level (global climate change).
4. Integration of small coastal mullets (striped, goldspot) with *Pangasius* culture will increase and diversify aquaculture species, and thus diversify dietary nutrition available to farming households.
5. Greater production of *Pangasius* will lead increases in employment opportunities in coastal communities, economies which are traditionally disaffected by global climate change events (*e.g.*, cyclone damage to fishing boats).

Plan of Work

Location

These studies will be performed in two districts of coastal Bangladesh, the Barishal district (Bakerganj Upajila village) and the Pauakhali district (Kotwali Upazila village).

Methods

1. Evaluate the growth performance of *Pangasius* catfish cultured in brackish (hyposaline) water.

This study will assess whether *Pangasius* catfish can be successfully cultured in the brackish water ponds of Southern Bangladesh (Barishal District), therefore the experimental design must reflect the surface water salinities in this farming region (2-8 ppt). Using ponds from participating farmers as well as those utilized for research by the Upazila Fisheries Office (Mr. Abdul Aziz), we will contrast *Pangasius* production under two salinity treatment ranges, each replicated with an on-site freshwater control group (T1). The proposed design is as follows:

Parameter	Treatment 1	Treatment 2	Treatment 3
Pangasius fingerlings	800 (2.0/m^2)	800 (2.0/m^2)	800 (2.0/m^2)
Salinity range (ppt)	0-0.5	2-5	>5-8
Feeding	std. regimen	std. regimen	std. regimen
Replicates (*n*)	6	3	3

Surface water salinities fluctuate extrinsically, and likely will not vary enough within a given locale to fully represent all treatment groups. Therefore, this design contrasts two salinity *ranges* at different test sites (T2 area 2-5 ppt, T3 area >5-8 ppt), with each also containing a freshwater control (T1) regulated from available ground water resources (additional site selection criteria). This will enable each of two treatments (n=3) to be contrasted against the current *Pangasius* culture practice (n=6). The availability of fresh well water also allows for the surface water salinity of the treatment ponds to be adjusted downwards, if needed due to high temperatures or drought. The historically stable hyposaline areas will be used for treatments T2 and T3.

All ponds (400 m^2) will be dried and limed (5 g/m^2 CaCO3) according to standard practice, and fertilized one week prior to stocking (28 kg N; 7 kg P/ ha). *Pangasius* fingerlings (7.5-10 cm) will be stocked in all ponds for a 180-day grow-out period. Fish will be fed commercial floating feed (30% CP; Mega Feed, commercially produced in Bangladesh) using a standard *Pangasius* feeding regimes: 10% BW from 0-30 days, 7.5 % BW from 30-60 days, 5 % BW from 60-90 days, and 3% BW thereafter. Feed amounts will be recorded for cost-benefit analysis performed at the end of study. Growth performance (weights/ lengths) will be taken by monthly sub-sampling of all ponds, with feeding rates adjusted at these times. Salinity, temperature, and water quality (turbidity, pH, alkalinity and DO) will be measured every week on site, with additional analysis of ammonia, nitrite, nitrate and phosphate performed at the Water Quality and Pond Dynamics Laboratory (BAU). Salinity treatment groups (T2, T3) will be tested for significant differences in growth (mean length and weight), growth efficiency (specific growth rates, feed conversion ratio), and water quality parameters with respect to the control group (T1) using One Way Analysis of Variance (ANOVA). A marginal cost-benefit analysis will be determined for each salinity trial incorporating total production yields (kg), expected market returns, feed and labor and other input costs.
Null Hypothesis 1: No difference in growth performance, water quality, or economic return is observed with Pangasius cultured at 2-5 ppt salinity compared to those cultured in freshwater.
Null Hypothesis 2: No difference in growth performance, water quality, or economic return is observed with Pangasius cultured at >5-8 ppt salinity compared to those cultured in freshwater.

2. Incorporation of coastal mullet species with *Pangasius* culture to increase household nutrition in coastal communities.

Using the results derived from Study 1, we will next identify whether *Pangasius* can be grown efficiently in polyculture with mullet (*Mugil cephalus*, *Liza parsia,* or both). Ponds (N = 12; 300 m^2) from the Patuakhali District will be utilized for this study, with specific site selection dependent on the salinity range (T2, T3; Exp. 1) yielding the best economic parameters for *Pangasius* monoculture (see Expt 1). The study will be performed with the following experimental design (n = 3):

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Pangasius Fingerlings	800 (2.0/m^2)	800 (2.0/m^2)	800 (2.0/m^2)	800 (2.0/m^2)
Striped Mullet	0	400 (1.0/m^2)	0	200 (0.5/m^2)
Goldspot Mullet	0	0	400 (1.0/m^2)	200 (0.5/m^2)
Salinity Range (Ppt)	best of Expt. 1	best of Expt. 1	best of Expt. 1	best of Expt. 1
Feeding	std. regimen	std. regimen	std. regimen	std. regimen
Replicates (*N*)	3	3	3	3

The proposed design contrasts *Pangasius* monoculture (T1) with the addition of one species or with mixed stocking of mullet (T2-T4) in brackish water ponds. Once the performance of each species of mullet is compared, then future studies can establish the stocking densities most appropriate for culture with *Pangasius*. The preparation and fertilization of ponds, stocking and feeding regimen for *Pangasius* will be performed as described in Experiment 1. Mullet seed will be collected from the coastal rivers (seeds abundantly available) with the help of the fishermen and stocked at a density of 1.0 fish/m^2. No additional feeds or fertilization will be used in this component, as we anticipate these fish will subsist upon primary production stimulated by initial fertilization (see Expt. 1) and also by some *Pangasius* feed inputs.

Growth and water quality measurements will be collected as described previously, with food amounts recorded daily for economic analysis. All treatment groups will be tested for significant differences in growth (mean length and weight), growth efficiency (specific growth rates, feed conversion ratio), and water quality using ANOVA. A marginal cost-benefit analysis will be determined incorporating total production yields (kg), expected market returns, feed and labor costs for these treatments.
Null Hypothesis: No improvement in growth, water quality, or economic returns is observed with Pangasius cultured together with brackish-water mullets.

Schedule

May to Oct 2014: Study 1; *Pangasius* catfish monoculture in brackish (hyposaline) water.
Apr to Oct 2015: Study 2; Polyculture trial of *Pangasius* with mullet in brackish water.
Jan to Aug 2015: Analyses, technical report, present results at the AquaFish Project Workshop.

Deliverables

1. Identification of the viable salinity range for *Pangasius* culture – growth metrics (specific growth rate, feed conversion ratio), feed costs, total production yield (kg) and estimated market return will be compared against freshwater culture (Study 1, T1) to identify whether *Pangasius* culture in hyposaline waters is economically viable. We anticipate equivalent production yields for at least the midrange (2-5 ppt) treatment group. The research trials will be done on-farm, and hence will directly benefit 12 participating farming households (~ 4800 m^2 of farming area) within the Host Country.
2. Improvements in Production Yield – Total production yield (kg) and estimated market return will be contrasted between *Pangasius* monoculture and polyculture with two mullet species (Study 2). We anticipate significant improvements in both yield and return with integrated *Pangasius*/mullet polyculture. The research trials will be done on-farm, and hence will directly benefit 16 participating farming households (~ 6400 m^2 of farming area) within the Host Country.
3. Improvements in Environmental Water Quality – Water quality parameters will be assessed and reported for all ponds used in Studies 1-2, and tested for significant differences. We anticipate significant improvements in environmental water quality in the *Pangasius*/mullet polyculture trials.
4. Documentation and Dissemination – Two students will receive training on *Pangasius* culture and its economic impacts as part of their thesis work. The findings from these studies will be documented through the Technical Reports of the AquaFish Innovation Lab, presentations through the AquaFish Innovative Lab Project Workshop, and peer-reviewed literature (1-2 manuscripts). Should technologies for hyposaline culture of *Pangasius* prove effective, then results will also be disseminated through production of an extension factsheet in the local language for wider outreach to farmers, extension agencies of the government, and NGOs.

COASTAL WOMEN'S SHELLFISH AQUACULTURE DEVELOPMENT WORKSHOP

Production System Design and Best Management Alternatives /BMA/13BMA01PU

Collaborating Institutions and Lead Investigators

University of Hawaii at Hilo (USA)	Maria Haws
University of Dar es Salaam (Tanzania)	Narriman Jiddawi
Western Indian Ocean Marine Sciences Association (WIOMSA) (Tanzania)	Julius Francis

Objectives

This workshop will bring together participants from coastal villages and technical assistance providers together to:

1. Provide training in bivalve shellfish culture methods;
2. Share results of the participatory research conducted as part of Investigation 1 and previous research; and
3. Develop an action plan for further development of the small-scale bivalve industry.

The majority of the participants in this workshop will be women and girls since they are the primary participants in shellfish farming. Although the technical focus for the workshop will be spat collection and the improved nursery methods (see previous investigation), the full range of bivalve shellfish topics will be covered. Site visits and hands-on training will also be included. Our standard workshop methodology is to minimize classroom learning and maximize the time spent with experiential learning.

Significance

This workshop will provide an opportunity to provide training and a venue to discuss research and training efforts provided as of the date of the workshop. Moreover, it will bring stakeholders together to develop an action plan to guide future efforts.

Activity Plan

The workshop will be primarily focused on women shellfish farmers and technical assistance providers. A two day workshop will be held during which the following topics will be addressed: 1) provide training in bivalve shellfish culture methods; 2) share results of the participatory research conducted as part of Investigation 1 and previous research; and 3) develop an action plan for further development of the small-scale bivalve industry. Furthermore, since climate change impacts have already affected the other primary mariculture activity in East Africa (seaweed farming), a preliminary plan for adaptation to climate change impacts will be included on the workshop agenda.

Schedule

The workshop will be held in Year 2, most likely in May or June 2014.

DEMONSTRATING THE VALUE OF TILAPIA AND SAHAR PRODUCTION IN POLYCULTURE PONDS USING GOVERNMENT FARM AND ON-FARM TRIALS

Production System Design and Best Management Alternatives/Experiment/13BMA06UM

Collaborating Institutions and Lead Investigators

University of Michigan (USA)	James Diana
Agricultural and Forestry University (Nepal)	Dr. Madhav K. Shrestha
Directorate of Fisheries Development (Nepal)	Rama Nanda Mishra

Objectives

1. To increase pond productivity through species diversification;
2. To demonstrate a carp-tilapia-sahar polyculture system for outreach potential by government fisheries development program;
3. To demonstrate the culture potential of sahar and tilapia to farmers; and
4. To develop partial enterprise budgets of costs and value of fish crops among treatments.

Significance

Total fish production in Nepal is 54,357 mt, with about 60% originating from aquaculture. Pond culture is the most popular method of aquaculture, but annual pond yield averages only 3.83 t/ha (DoFD, 2012). Carps are popular warmwater fish for culture in Nepal, contributing more than 99% of aquaculture production in the country. Tilapia, which is also referred to as the aquatic chicken, is a globally prominent species for all types of management intensities. Nile tilapia (*Oreochromis niloticus*) was introduced into Nepal in 1985 (Pantha, 1993), but it remained under government control for more than 10 years (Shrestha and Bhujel, 1999). Since 1996, experiments conducted at IAAS included polyculture of tilapia and common carp (Shrestha and Bhujel, 1999), mixed-size culture of tilapia (Mandal and Shrestha, 2001), and polyculture of grass carp and tilapia (Pandit et al., 2004). As mixed-sex tilapia is most commonly used for culture, recruitment control remains a problem. Snakehead (Yi et al., 2004) and sahar (Shrestha, 1997) have been evaluated for their ability to control tilapia reproduction by predation on tilapia fry. Tilapia and sahar co-culture was attempted to control excessive recruitment of tilapia and also to provide an additional species to increase productivity of high valued fish that are indigenous (Shrestha et al., 2011). Experiments indicated that sahar can control tilapia fry production (Poudel et al., 2007; Rai et al. 2007, Yadav et al., 2007; Shrestha et al., 2011). Growth of sahar was higher in tropical and subtropical ponds than in cages reared in Pokhara lakes and also suspended cages in ponds (Bista et al., 2001, 2007; Shrestha et al., 2005, 2007). Sahar has been overfished in rivers and lakes, which has resulted in declining populations (Rajbanshi, 2001; Joshi et al., 2002; Rai et al., 2007).

Semi-intensive carp polyculture is an established system in the tropical and subtropical regions of Nepal, using fertilized ponds with supplemental feed. The carp species include common, silver, bighead, grass, naini/mrigal, and bhakur/catla. All six species are recommended in certain ratios with a combined density of 15,000 fish/ha, but fingerlings of all species are rarely available when needed for stocking. The typical number of species cultured ranges from four to six. The addition of other proven species (such as tilapia and sahar) with increased stocking density into the existing carp production system could increase productivity up to 57% and net returns by 61% (Shrestha et al., 2012).

The addition of new species to the carp polyculture system fits both the national aquaculture plans elaborated by government agencies as well as the *Feed the Future* plans for aquaculture improvement. The first FTF research goal is to advance the productivity frontier by both increasing productivity beyond current levels through technology development, and extending technology so that local production can reach the level of research farms. This proposal will focus on both of those goals. Secondly, the national plans for aquaculture and fisheries have goals to improve culture of indigenous fishes, as well as to raise yield of ponds from farms to the level of research stations (GoN 2000, NARC 2010). Again, this project is in complete alignment with those goals.

This study is intended to expand the technology developed through AquaFish CRSP research on carps, tilapia, and sahar production to farmers in order to demonstrate alternative fish production models. In particular, we will produce fish in a polyculture system on a government farm using all six species, and determine the partial enterprise budget for the production system. After this demonstration, we will conduct an on-farm experiment on polyculture systems, using carps, with addition of tilapia or tilapia and sahar to determine the most practical system for farm adoption.

Quantified Anticipated Benefits

The results of this study will provide two additional species in the polyculture system of Nepal, which should increase production and income. It will add high valued fish to the culture system and supplement income. As carp polyculture is established, the increasing species will be easier to adopt by fish farmers. It will also help in production of sahar, which could be stocked in natural waters to reverse population declines. It will benefit fish culture in south Asia and other countries where carp culture is popular. The immediate impact will be measured by the increased production and economic returns in on-farm trials for the different polyculture systems. We expect to improve yield and economic returns for polyculture systems by at least 30% with these additions, and train at least 5 farmers in the new production system. We will document these benefits through the on-station trials and subsequent surveys of farmers who attend our training sessions.

Research Design and Activity Plan

Location

Fisheries Development Center, Bhairahwa and Dayanagar, as well as farm ponds in fish production pockets of the Rupandehi district.

Methods

Pond Demonstration

- Pond facility: 15 earthen ponds of 200-500 m^2 will be used for both government (on-station) and on-farm ponds.
- Culture period: 10 months each.
- Test species: Carps (Common, Silver, Bighead, Grass, Rohu, Mrigal and Catla), Nile tilapia (mixed sex) and Sahar
- Stocking: Carps (5-10 g) at 15,000/ha; Mixed-sex Nile tilapia (5-10 g) at 3,000/ha; Sahar (5-10 g) at 1,000/ha
- Nutrient input: Fertilization and daily feeding with locally made feed at 2% BW
- Water management: maintain at 1 m deep.
- Sampling schedule
  - Water quality: Biweekly measurement of temperature, DO, pH, transparency
  - Fish growth: monthly sampling
- Statistical design, null hypothesis, statistical analysis:
  - This is a demonstration and has no treatments and no statistical analyses. Comparisons will be made between this growout system and previous polyculture results.

On-farm trial

- The on-farm trial will include three treatments with five replicate ponds each. Most methods will be similar to those listed above. The treatments will be:
  - Existing carp polyculture (15,000/ha) (control)
  - Control + tilapia (3000/ha)
  - Control + tilapia (3000/ha) + sahar (1000/ha)
- Sampling Schedule

    - Water quality will be measured at initiation and harvest times in each pond using CRSP protocols.
    - Fish growth and yield will be measured from stocking to harvest. Partial enterprise budgets will be estimated for overall production results of each treatment.
- Statistical design, null hypothesis, statistical analysis
    - The trial will be conducted in a completely randomized design, and data will be analyzed using one-way ANOVA.
    - Null hypothesis: Introduction of tilapia and sahar in carp polyculture has no effect on growth, production, or economic return in different polyculture systems.

Schedule

On-station April to November 2014 on-farm April to November 2015. Final report no later than August 2015. On-station training will begin in April 2015 and continue indefinitely.

NEW APPROACHES TO INFORM, MOTIVATE, AND ADVANCE SMALL AND MEDIUM-SCALE FISH FARMERS: BUILDING INDUSTRY CAPACITY THROUGH CELL PHONE NETWORKS, TRAINING, AND MARKET PARTICIPATION

Production System Design and Best Management Alternatives/Experiment/13BMA04AU

Collaborating Institutions and Lead Investigators

Auburn University (USA)	Joseph J. Molnar
	Claude Boyd
University of Georgia (USA)	William Tollner
Makerere University (Uganda)	Monica Beharo
	Theodora Hyuha
NaFIRRI (Uganda)	Gertrude Atukunda

Objectives

1. Assess fish farmer needs and expectations for cell phones as a source of information, technical guidance, and applications.
2. Develop a program of technical collaboration among researchers, government technical staff, and cellular providers to advance aquacultural development.
3. Build on existing farmer-based institutions to use national trade shows, train-the-trainer, symposia and other events to stimulate value chain development and attention to proven production practices.

Significance

Improving agricultural productivity is one of the most pressing issues for developing regions. Although mobile phones are no silver bullet, their widespread availability and flexibility position the technology as a necessary component of sustainable improvements in aquaculture. Coupled with corresponding innovation in existing social and institutional arrangements, mobile phones have the potential to make significant contributions to increase income for small-scale fish farmers. As mobile phones converge with other mobile devices such as netbooks and tablets, the opportunities will proliferate. Affordability will remain an issue, but cell phone capability and market penetration will grow.

Mobile phones seem to influence the commercialization of farm products. Subsistence farming is notoriously tenuous, but smallholder farmers, lacking a social safety net, are often highly risk averse and therefore not very market oriented. A study from Uganda found that market participation rose with mobile phone access (Muto and Yamano 2009). Although better market access can be a powerful means of alleviating poverty, the study found that market participation still depended on what producers had to sell. Perishable bananas were more likely to be sold commercially than less-perishable maize.
Old style extension approaches must be supplanted (or at least supplemented) by mechanisms that provide for widespread dissemination of technical information to stimulate and support the adoption of productivity increasing practices. Cell phones are already recognized as powerful tools in food production. Technical guidance, product assembly, and price discovery are but three of the many fundamental applications of communication advances in aquaculture. Fishers and farmers use cell phones to get market prices to know where to sell products. Fish farmers use them for extension support and to arrange for feed and seed.

Cell phones are quickly transforming markets in low-income countries. One study assessed the impact of mobile phones on grain market performance. Aker (2008) finds that the introduction of mobile phones is associated with a 20-percent reduction in grain price differences across markets, with a larger impact for markets that are farther apart and those that are linked by poor-quality roads. Cell phones also have a larger impact over time: as more markets have cell phone coverage, the greater the reduction in price differences. This is primarily due to changes in grain traders' marketing behavior: cell phones lead to reduced search costs, more market information and increased efficiency in moving goods across the country.

In one system for coffee producers, SMS messages are sent to users' mobile phones every morning with the offers and grades available for purchase on that day. At the end of the day, users receive a text message with details of what actually took place. The Kenya Marine Fisheries Service is developing a SMS system for sharing marketing data from fish landings and other marketing points. Other applications in aquaculture may include sourcing the availability of fingerlings, placing orders for seed stock, and otherwise coordinating stocking and harvesting of fish.

In Malawi, Katengeza et al. (2013) found cell phone use positively affected by literacy, distance to local market, land size, current value of assets, crop income, and region. Intensity of use is conditioned by gender, participation in agricultural projects, and ownership of a mobile phone, current asset value, and distance to nearest public phone services. Asset endowment plays a critical role in enhancing adoption of mobile phone technology. Gender disparities significantly affect adoption as most women have limited access to assets. In Kenya, M-Farm is a mobile service that connects farmers with one another, because peer-to-peer collaboration can improve market information and enhance learning opportunities (World Bank 2013). These services are intended to improve agricultural marketing, particularly for women.

The Village Phone program provides microloans to rural entrepreneurs who purchase a mobile phone, long-range antenna, solar charger, and airtime (World Bank 2013). The recipient earns a livelihood by operating a phone kiosk in areas underserved by mobile networks. As is typical in microfinance, the loan recipients tend to be women.

Martin and Abbott (2013) examined the diffusion and perceived impact of agricultural based mobile phone use among small to medium size limited resource farm holders in Kamuli District, Uganda, where 42% of farm households now have a mobile phone, more than half of the farmers were using their mobile phones for farm purposes. The sought agricultural inputs, obtained market information, monitored financial transactions and used it for agriculture emergency situations. Slightly less than half were consulting with experts via mobile phones.

Men tended to adopt mobile phones earlier than women and those with more education were more likely to use SMS (short message service) text features. Women were less likely to use the calculator function, perhaps due to a lack of numerical literacy training. Those who were members of agricultural groups were more likely to use their mobile phones for a variety of purposes. The study identified a number of unique uses being made of mobile phones, including taking photos of agricultural demonstrations, using the loudspeaker function to permit a group of farmers to consult with an expert, recording group members pledging when they will repay loans, and storing data such as the date hens should start laying eggs (Martin and Abbott 2013).

Although mobile phones continue to evolve quite rapidly, the evidence suggests that they can promote improved livelihoods through networking and informing previously unconnected portions of the population. The evidence comes from users' own rapid grasp of the technology's potential (Kerala's fishers using phones to seek optimal markets for their catch) and from planned efforts originating from commercial information providers and development practitioners (as in market information and insurance programs).1 Price information is more complicated than it might seem. Bid, Asked versus actual strike prices where money and fish change hands are quite different things. The question is: can cell phone networks help provide some order, transparency, and certainty to aquaculture markets in Africa?

[1] http://www.ictinagriculture.org/sourcebook/module-3-mobile-devices-and-their-impact

The present study develops base information about the needs and interests of fish farmers in order to induce public agencies, nongovernmental organizations, and cellular service providers to facilitate the use of cell phones as a means to guide, coordinate, and instruct fish farmers.

Quantified Anticipated Benefits

1. Availability of text-based fish market and fingerling supply information
2. New extension mechanism for reaching fish farmers on broad-scale
3. Augmented value chain for tilapia and other species resulting in added farm-level income

Research Design and Activity Plan

One study and two activities are planned.

Study 1. Cell-based Information Needs Assessment:

We use qualitative approaches to map the aquaculture knowledge and information system.

Location of work

Objective 1 will be addressed through a series of six focused group interviews conducted in focal fish farming regions across Uganda.

Methods

We will work with area fisheries officers to assemble 8-12 active fish farmers to participate in focused group interviews cell phone use in aquaculture. The most common purpose of a focus group interview is to provide an in depth exploration of a topic about which little is known. For such exploratory research, a simple descriptive narrative is quite appropriate and often all that is necessary. It is common for focus group interviews to be used for purposes of developing hypotheses that are then tested or validated with other types of research. For example, a focus group may yield hypotheses that are tested through a survey of the population of interest. The main deliverable for this study is a report summarizing the main themes and perceptions of the participants (Stewart 2013).2

Trained Ugandan graduate students will lead the interviews in local languages. Teams of interviewers will lead the discussion following a flexible format based on an interview guide of topics develop from the literature and previous experience in Uganda. The notes, observations, and verbatim quotations will be compiled in English with translation as appropriate. We envision at least one Makerere M.S. thesis will emanate from this work.

Study 2. Cell-based Information Supply Development:

Objective 2, the project will hold a series of three small conferences in selected locations where agricultural cell-based information systems are in operation or advanced stages of development. One of the conferences will be exclusively focused on cell phone access, use, and potential among women.

Location of work

Three day-long conferences will be held in Gulu, Jinja and Kampala and will bring together NGO technicians, public agency personnel, and project participants in a series of presentations, dialogues, and convergent prediction exercises that will inform and guide subsequent efforts to design and deliver cell-based information.

One of the conferences will be exclusively focused on cell phone access, use, and potential among women. We will seek to involve women professionals from the cell phone industry, women in aquacultural businesses and farming, and women professionals from the civil service serving agriculture. The workshop objectives are to elucidate the ways that women lead and participate in aquaculture, to identify emerging uses and applications that are particularly helpful to women, and to suggest paths for

[2] http://www.sagepub.com/upm-data/11007_Chapter_7.pdf

technology development and government service that will be particularly beneficial to women in aquaculture.

Methods
We will use focused group interview techniques to address an established list of topics, albeit in the order of the group's interests, experiences and capabilities. The material will be transcribed by graduate students and the content organized as a database to be sorted and analyzed with Atlas.ti or similar program. The report will summarize the perspective of knowledge information industry participants about the way forward for cell phone technology in Uganda.

Study 3. Advancing Aquaculture Industry Development
Location of work
Training events will be held at various locales to advance the development of the aquaculture industry in Uganda. —The primary venue will be the Annual Fish Farmer Conference and Trade Show that is usually held in Kampala.

Methods
A central feature of underpinning the growth of aquaculture production and expertise in Uganda is the Annual Fish Farmer Conference and Trade Show. The project will continue to support the event through participation of project personnel and outside speakers. To complement this event, we will hold a training session for selected, invited trainers from other projects and organizations that will focus on water quality and environmental management issues in aquaculture. Auburn University Professor Dr. Claude Boyd will lead this annual 1.5 day training event.
We also will hold a technical symposium on new approaches to technical assistance in aquaculture to link representatives of cellular providers, projects, nongovernmental organizations, and public agencies in Kampala. This meeting will be held as an event immediately preceding the Annual Fish Farming Conference and Trade Show. The meeting will provide a venue to sharing experience and expertise in the broader context of agriculture with the intent of using the models and experiences as guidance for services for fish farmers. University of Georgia Engineering Professor Dr. E.W. Tollner will provide leading presentations and participate in the discussion. He also will provide lectures at Makerere University to faculty and students on pond construction, water management, and other engineering aspects of aquaculture.

Schedule

Task	8/2013	11/2013	2/2014	5/2014	8/2014	11/2014	2/2015	5/2015	
Focus groups	x	x	x	x					
Technical conference		x	x	x					
Training					x	x	x	x	

Deliverables

Item	Mechanism (e.g. podcast reports factsheets etc.).
Results of focus groups	Journal article
Farmer leaflet	Tip sheet for farmers
Training program on fish production	Joint exercise with Chinese donor group at Kajjansi
Review of MU's aquaculture curriculum;	Report chapter from joint exercise with Makerere faculty and administrators resulting
MU aquaculture degree strategy (undergraduate and/or graduate);	Report chapter from joint exercise with Makerere faculty and administrators resulting

Needs assessment for MU farm training facility with aquaculture ponds.	Report chapter from joint exercise with Makerere faculty and administrators resulting

TOPIC AREA

SUSTAINABLE FEED TECHNOLOGY AND NUTRIENT INPUT SYSTEMS

❖

ASSESSMENT OF GROWTH PERFORMANCE OF MONOSEX NILE TILAPIA (*OREOCHROMIS NILOTICUS*) IN CAGES USING LOW COST, LOCALLY PRODUCED SUPPLEMENTAL FEEDS AND TRAINING FISH FARMERS ON BEST MANAGEMENT PRACTICES IN KENYA

Sustainable Feed Technology and Nutrient Input Systems /SFT/13SFT06AU

Collaborating Institutions and Lead Investigators

University of Arizona (USA) — Kevin Fitzsimmons

Kenya Ministry of Agriculture, Livestock and Fisheries — Charles C. Ngugi, Judy Amadiva, Julius Nyoro, Mwangi Mbugua

Objectives

1. Develop low-cost, improved quality feeds utilizing rice bran and freshwater shrimps (*Caridina nilotica*) as fishmeal replacement.
2. Evaluate the growth performance of monosex Nile tilapia under three different feeding regimes in cages.
3. Transfer technologies on management of monosex tilapia in cages through training farmers and extension officers.
4. Compare work conducted in this investigation on the use of low-cost supplemental feeds with the accomplishments of 20 years of CRSP-related work in the area.

Significance

Expensive commercial feeds represent the most significant operating cost for intensive tilapia aquaculture in Kenya. Finding lower cost ingredients capable of supplying adequate protein and nutrition is a major goal of fish nutrition research. In many developing countries, fishmeal, the most common protein source in prepared fish feeds, is expensive. Using alternative sources of protein would help reduce the costs of feed inputs and increase income for small-scale fish farmers.

Certain composted organic materials are a potential source of protein for aquaculture feeds. Sumagaysay (1991) demonstrated that composted rice straw could be used in milkfish diets and Ray (1992) reports that composted *Salvinia cuculata*, an aquatic weed, could be used in Indian carp diets. In Kenya, agricultural by-products could be used as cheap, high-nutrient components of locally produced fish feeds. Rice-bran is widely available and could be combined with a low-value fish species, such as freshwater shrimp (*Cardina nilotica*), to produce the nutritional base for locally sourced, sustainable fish feeds.

Another obstacle to income generation for small-scale tilapia farmers is prolific breeding that occurs due to precocious maturity when males and females are reared concomitantly. Ponds stocked with both sexes can result in the production of small fish of little market value. The technology needed to breed monosex, all male, fry is not available, or is too complicated for the average fish farmer. Using monosex tilapia will improve productivity by eliminating the incidence of precocious maturity and allow fish to grow more rapidly to the desired market size.

Another improvement that can be made to increase income generation among small-scale fish farmers is implementing cage culture systems. These systems areknown to require a larger capital investment, but returns are much higher than static pond culture systems. However, low cost quality feeds are needed in ponds and cages when farmers wish to produce more fish than can be supported from fertilized (extensive) systems. This is largely because fish stocked in cages do not have access to the entire water body for feeding, and require more intensive inputs to achieve adequate nutrition. Improvements to the feed manufacturing ability of cluster farmers will facilitate development of cage culture systems in the country, which will in turn increase productivity.

Many small farmers will be encouraged to build and utilize cages to increase their household income and nutrition. After construction of the cage, cost of feed becomes the major input cost for fish production. Complete formulation diets are available but are quite expensive. Introduction of supplemental feeds using low-cost, locally available protein sources would remove the constraint of access to commercial feeds and develop markets for freshwater shrimps and agriculture by-products, such as rice bran. Introducing pelleting technology will greatly improve feed stability and quality.

Experimental Design

The null hypothesis to be tested in this experiment is as follows:
The growth performance of monosex Nile tilapia using low cost improved feed is not different from the growth performance using standard commercial feed.

We will develop and test low-cost feeds utilizing locally available ingredients and pelleting technology in grow-out trials of monosex tilapia in cages. Diet formulations utilizing freshwater shrimps and rice bran will be prepared using motor-driven pelleting equipment. Feed will be prepared on commercial pelleting equipment fabricated and distributed to cluster farmers. The experimental feeds will be tested for stability in water and proximate analysis at the University of Nairobi. Feeding trials will be conducted with monosex tilapia reared in cages at the farm. Initial stocking rates for the cage trials will be 50 fingerlings per m^3, with an expected harvest size of 500g each over a period of six to eight months depending on temperature regimes.

During the grow-out trials, twenty fish per replicate will be sampled monthly. Growth, survival, and cost of production will be determined for fish on experimental diets and the control ponds. Water quality parameters including dissolved oxygen, pH, nitrogen (ammonia, nitrates and nitrites) and turbidity will be examined on a weekly basis. The cage trials will receive the pelleted diet under three formulated regimes. Four replicates of cages measuring $2m^3$ will be used for each treatment and the control. They will be suspended in a pond whose water runs through so as to maintain high oxygen levels. The null hypothesis that the fish will all have equal growth will be tested with ANOVA at 5% confidence limit. The tests will be performed with the assistance of Minitab Version 14 or a comparable software package.

Quantified Anticipated Benefits

The research described below addresses several constraints mentioned in the AquaFish Innovation Lab proposal. One research priority is in the area of environmental impacts and effluent control. Other experiments attempt to further improve biological and technological knowledge of pond systems, specifically best management practices and the use of technologies in production systems.

Supplementary activities concentrate on human capacity development, especially extension of aquaculture information to local farmers in the country. Increased tilapia and other warm water fish production from pond and cage systems would be applicable to most tropical and sub-tropical regions. Using low cost ingredients will allow small producers to rear more fish in a limited area without investing money in expensive nutritionally complete diets. Pelleting technology will provide a pellet that will have greater stability in the water and allow the fish to get the full benefit of the feed ingredients. Pelleting also reduces the production of fines that are not available to the fish and can degrade water quality.

Furthermore, the research has the potential to improve gender integration in aquaculture by involving women in the sourcing, processing, and manufacturing of pelleted feeds. This part of the production chain would be transferred from commercial feed factories to the harvesters and their associates, creating a great opportunity to expand women's involvement in the aquaculture industry.

Identification of Beneficiaries

Tilapia producers in the Kenya would be the most immediate beneficiaries of the development of low cost feeds. Consumers of fish should be beneficiaries of larger volumes and lower cost farmed fish. Suppliers of freshwater shrimps and rice bran would benefit as new markets develop for their products.

Impact Indicators and Targets

- Twenty small-scale farmers adopting use of monosex production practices
- Twenty fish farmers adopting cage culture system technology
- Fifty fish farmers trained in use of low cost feeds and monosex culture
- Five extension officers trained in use of technologies and best practices

Collaborative Arrangements

Earthen ponds, round tanks, and a wet lab are available for this study. Graduate students will construct cages from locally sourced materials. Trained technicians and extension specialists will be available to support and extend the research. Mwea Aquafish Farm will provide the pelleting equipment, lab facilities for water and feed analyses, and stocks of monosex tilapia that will be used for production trials in cages.

Schedule

November 2013:	Select graduate students, obtain pelleting machine and make cages
December 2013:	Select spawners for production of fry (HC PI will leverage cost)
February–March 2014:	Collect tilapia fry/fingerlings and begin hormone treatment
April- 2014:	Annual meeting to be determined
May- October 2014	Feeding and sampling
October 2014:	Training cluster fish farmers and extension officers on BMPs
November 2014:	Harvest ponds and cages, collect data
December 2014:	Second farmers training
February 2015:	Annual meeting to be determined
March 2015:	Analyze data and prepare reports
June 2015:	Submit Final Reports and journal articles

Deliverables

Item	**Mechanism (e.g. podcast reports factsheets etc.).**
Low-cost feeds	Manuscript describing uses and applications
Training on BMPs	Training report
Results of trials	Journal article

FORMULATION AND MANUFACTURE OF PRACTICAL FEEDS FOR WESTERN KENYA

Sustainable Feed Technology and Nutrient Input Systems /SFT/13SFT07AU

Collaborating Institutions and Lead Investigators

University of Arizona (USA)	Kevin Fitzsimmons
Eldoret University (Kenya)	Julius Manyala
Kenya Ministry of Agriculture, Livestock and Fisheries	Charles C. Ngugi

Objectives

1. Develop a practical tilapia feed formulation from locally available ingredients.
2. Evaluate growth rates of tilapia fed locally formulated feed versus standard commercial feed.

Significance

Feeds represent more than 50% of the production cost for tilapia farming in Western Kenya. As such they present a significant determinant of the ability of small-scale fish farms to generate income for households. With the diverse agricultural base in Kenya, most typical ingredients for fish feeds are available. However, the costs can be high and the quality uneven (Liti et al. 2005, Maina et al. 2002). The particulate sizes for several of the typical ingredients are variable and unacceptably large for inclusion in a pellet. The uneven ingredient size will reduce both pellet stability in the water and digestibility by the fish, both of which can negatively affect water quality and feed conversion rates.

Quantified Anticipated Benefits

Our partners in Kenya tell us that the lack of quality pelleted feeds is a primary constraint to the industry. We anticipate that better feeds will benefit farmers who will be able to increase fish production by at least 10% and improve feed conversion ratio (FCR) by 50%. We will contact our farmer cooperators to determine the exact figures on productivity and FCR. The benefits of greater productivity and FCR are key to profitability. Ease of handling and accuracy in feeding are more difficult to quantify, but we will also ask farmers to estimate time savings and reductions in wasted feed from reduced feeding frequency and higher FCRs.

Experimental Design

Task 1. Develop a practical tilapia feed formulation and develop manufacturing practices that increase the stability of pelleted feeds in water.

We will gather cost and availability data on local soybean oil meal, soybean cake, wheat, wheat mids, wheat bran, broken rice, rice bran, sorghum, sunflower meal, safflower meal, sesame meal, corn, corn meal, vegetable oils, fishmeal and fish oils, binders, anti-oxidants, vitamins, minerals and other ingredients that might be utilized in a tilapia diet. We will use feed formulation software to develop a practical diet based on nutrient components. Then we will use a grinder / hammer mill to reduce particle sizes to a powder consistency if they are not delivered as such. There are several diet formulations that are currently used when mixing ingredients that are sold as a mix that is broadcast on the surface of ponds. These diets, at best, provide a 4 to 1 FCR. We expect that simple pelleting of these same ingredients should improve the FCR to 3:1. With better formulation and pelleting, we hope to improve FCR to 2:1.

We will experiment with different flow rates through the mill to determine optimal throughput for the various ingredients. We will also experiment with levels of water to determine the moisture content that will facilitate material flow through the pellet mill. This will obviously also impact the moisture content of the pellet and require adjustment of the drying process. For the current time, we will focus on solar drying to prepare the pellets. If funds are available or equipment can be borrowed, we will develop a forced air drying system. The primary objective will be to produce a pelleted feed that has increased stability in water. The pellets will first be tested for water stability using the standard method (Fagbenro and Jauncey, 1995) to determine if the pellet will maintain its form for at least 5 minutes. Assuming that the dietary pellets are not significantly different in stability, we will conduct a feeding trial. If a diet is significantly less stable, we will reformulate and prepare an additional diet that will meet the stability threshold.

Task 2. Obtain low cost grinding mill, mixer and pelletizer to form pelleted diets.
We will consider purchase of used machines from the US or Kenya, or new machines from India or China. These items should be available in the range of a few hundred dollars each. Eldoret University will provide a location for the machines and space for safe storage of ingredients. The grinding mill will be used to reduce particle sizes to less than 0.5 millimeter. A bakery or paddle style mixer will be used to develop a uniform mixture of the various ingredients. The mixer will also ensure that liquids (oils, water, anti-oxidants) are evenly distributed and coating all the particles. The pellet machine will be hand fed and auger driven with a variety of dies to determine pellet diameter.

Task 3. Test the newly formulated pellet feeds against readily commercially available pellet feed(s) in ponds at University of Eldoret in Kenya.
The various pellets that are prepared on the pellet mill will be stored until we have developed 5 diets to be tested concurrently. These five diets will be tested against (at least) one commercially available and readily used feed/diet. Eighteen hapas will be used with three replicates for each diet to be tested. The diets will be randomly assigned to the hapas to reduce position effect of the hapas within the pond. Equal numbers of fish with equivalent biomass (approximately 40g each) will be fed the test diets for a period of 42 days. Growth rates and percent survival will be compared by ANOVA and Duncan’s multiple range tests to determine if there are any statistical differences at a 0.05 p level.

Impact Assessment
We expect that simple improvements in formulation, better grinding of ingredients and simple compression pelleting of feed will significantly improve FCRs, and that this can be achieved at minimal additional cost. If these techniques are proven successful in the lab, our expectation is that private sector enterprises will purchase similar equipment and commercialize the procedures almost immediately.

We plan to use similar methods to disseminate the results of the feeding trials to two different audiences: 1) small-scale farmers, and 2) feed manufacturing companies. Both of these stakeholders will receive leaflets (or whatever method of outreach is deemed most appropriate and effective). For the small-scale farmers, the focus will be on which types of feed have the highest FCR and the cost of each formulation. Farmers will be encouraged to contact their local fisheries/aquaculture agent (or a similar agent) who can direct them to manufacturers in the area where they may buy the newly formulated feed. For the feed producers, outreach materials will focus on the equipment used and the feed formulations so that they can replicate the recipes for commercial sale.

Schedule

July 2013	Obtain formulation software and grinder
August 2013	Obtain mixer and pellet mill.
September 2013	Formulate and manufacture first diets
October 2012	Complete 5 diets and test stability
November 2013	Stock hapas and begin trial
January 2014	Complete harvest data collection
February 2014	Conduct second trial
April 2014	Complete harvest data collection
May 2014	Compile results and analyses
June 2014	Prepare and submit final reports

Deliverables

Item	Mechanism (e.g., podcast reports factsheets etc.).
Results of diet stability tests	Manuscript
Results of feeding trials	Leaflet for farmers
Results of feeding trials	Leaflet for feed manufacturers
Results of feeding trials	Journal article

ALTERNATIVE FEEDS AND PROCESSING FOR FRESHWATER AQUACULTURE SPECIES

Sustainable Feed Technology and Nutrient Input Systems /SFT/13SFT03UC

Collaborating Institutions and Lead Investigators
University of Rhode Island (USA) Dr. David Bengtson
Can Tho University (Vietnam) Dr. Tran Thi Thanh Hien

Objectives

1. To continue the development of cost-effective alternative feeds for carnivorous freshwater species for small-scale farming of snakeheads by women during the flooding season; and
2. To improve the processing activities for added value of cultured snakehead products, particularly for women.

Significance

Aquaculture of freshwater carnivorous and omnivorous fish species in Cambodia and Vietnam is highly dependent on inland fisheries of low value fish for sourcing key dietary nutrient inputs. Adequate pelleted diets, with minimal content of fishmeal (FM), are needed to overcome the use of small-size fish (SSF) harvested from the Mekong for aquaculture. The surveys of our CRSP project in the Mekong Delta (Phase 1) which were conducted in 2008-2009 showed that only 1.64% of snakehead farmers applied pelleted feed. From 2007-2012 researchers at Can Tho University (CTU) in Vietnam, working with US collaborators at the University of Rhode Island (URI), developed a formulated feed that reduces the use of SSF and FM content without decreasing growth performance and marketability. In a series of studies, CTU researchers developed hatchery protocols for weaning of snakehead from live to formulated feeds and then developed a formulated diet that minimized FM content due to replacement with soybean meal (SBM), rice bran and cassava meal. The best diet was tested in the field in comparison with the traditional SSF diet in ponds. Fish fed the pellet diets survived and grew as well as the SSF-fed snakehead and an evaluation panel could detect no significant differences in the quality of the final fillet. Starting when the snakehead are 30 days old, farmers can now use a pelleted feed containing 40% plant protein. Results of the research were disseminated directly to feed manufacturers, one of which actually produced the AquaFish CRSP diet and supplied more than 200 snakehead farmers. Ten aquaculture fish feed manufacturers in the Mekong Delta now make pellet diets containing a mixture of fishmeal and soybean meal. In 2011, more than 33% of snakehead farmers in 13 provinces of Vietnam were using these diets instead of SSF, thereby reducing fishing pressure on the low-value fish in the Delta. In An Giang and Dongthap, mainly snakehead culture provinces, about 500 farmers apply pelleted feed.

As exciting as these results are, problems remain. SBM contains anti-nutritional compounds that limit the amount of SBM that can be included in diets. However, another soy product, soy protein concentrate (SPC), is missing those anti-nutritional compounds due to an ethanol extraction of them in the production process. Interestingly, researchers at URI have found that summer flounder that have been fed SBM-FM diets survive better in a bacterial challenge than do flounder that have been fed either SPC-FM or FM (control) diets. That indicates that something in SBM acts as an immunostimulant. URI researchers are currently isolating and identifying that (those) compound(s) with funding from RI Sea Grant. Summer flounder can tolerate much higher levels of SPC in their diets than they can SBM. It may be that SPC can completely replace FM, as has been shown for cod (Walker et al., 2010). If so, an SPC diet, with added immunostimulant extracted from SBM, should yield excellent growth of fish plus increased resistance to disease.

Scenarios of climate change and/or damming of the Mekong River could greatly impact the availability of fish-based products for inclusion in diets for snakehead. Soy-based products would still be available however. Furthermore, from the international commodity perspective, FM is both very expensive and subject to variable availability that causes price spikes. SPC is less expensive and not subject to such variability. For these reasons, development of snakehead diets with maximum inclusion of SPC and added immunostimulants should represent a more sustainable future for snakehead aquaculture.

Women make up more than 50% of the population in the Lower Mekong Basin (LMB). Our previous studies showed that male labor was dominant in fish farming practices (78.4% of farmers), but the participation of women in the farming snakehead species was high (21.6% of farmers) in comparison with other cultured fish species in Vietnam (often less than 10%) (AquaFish-CRSP project, 2010). The role of women in the value chain of snakehead fish in Vietnam is more important in trading and processing activities of snakehead products. AquaFish-CRSP (2010) reported that in the LMB of Vietnam 26.7% of snakehead traders were female while the figures were much higher in the cases of processing and retailing activities with 90.9% and 93.3%, respectively. In addition, low educational level has been considered one of the constraints for improvement of the value chain of snakehead fish. About 10.1% of fish farmers were illiterate while the respective numbers for processers and retailers were 9.1% and 10.5% (AquaFish-CRSP project, 2010).

In the flooding season, changes in the hydrological regime (water levels, duration of flooding, timing of flooding) affects aquaculture in LMK. Since 2010, Can Tho University has developed small-scale aquaculture for flooding areas, especially small-scale farming of snakeheads in hapas and plastic tanks. These models were judged to be very effective for flooding seasons and women participants (more 70% women participant). However, small-scale farmers of snakeheads still use small fish for feeding. So, developing the small-scale farming of snakeheads using formulated feed is very necessary for environmental control and aquatic resources management.

In the first two phases of AquaFish-CRSP, all research activities related to the improvement of processed products of snakeheads were conducted in Cambodia (captured snakeheads, only), but not in Vietnam (where processing can be done with cultured snakeheads). Snakeheads can yield many processed products that can be stored for a long time. It is beneficial to offer more technical training and to improve the supply and the use of pelleted feeds in association with improving the quality and added value for processed products. Furthermore, improvement in the organization and management of production of products, including policy to support the processors for further development of markets, especially export markets, would greatly improve this value chain.

Quantified Economic Benefits

The results of this study will provide information on alternative diets for snakehead, especially those diets that reduce/eliminate FM use and improve fish health, in order to build a long-term sustainable industry. Through an economic analysis of costs and benefits of the diets (based on costs of FM vs. SPC and survival/growth of fish with improved health) optimal diets for use in small-scale snakehead culture will be identified. The results will also increase the small-scale farming and processing activities of snakeheads for the women in the flooding season. The results will improve the processing activities for added value of cultured snakehead products. Detailed economic analyses of small-scale farming and processing activities of snakeheads for the women in the flooding season are currently lacking. We will conduct surveys at the beginning of the project to estimate economic activity and profitability of these operations, then conduct surveys at the end of the project to quantify the economic benefits resulting from the adoption of the practices that we introduce.

These experiments allow the U.S. Participant in this investigation, Dr. David Bengtson, to expand his studies of plant protein replacements for fishmeal from temperate to tropical species.
The experiments will result in undergraduate and graduate thesis research at CTU, providing further capacity building in trained graduates who will work in the aquaculture industry in the Lower Mekong

Basin. Finally, further adoption of soybean-based diets by the snakehead industry will provide increased markets for operators of feed-mills and potentially for the U.S. soybean industry.

Research Design and Activity Plan

Location of work:

- Formulation of diets will be done through collaboration between CTU and URI based on information about chemical composition of ingredients. Manufacture of the diets will be done at CTU, which has a small fish-feed mill (for floating feed, 200kg/hour), as will analysis of diet composition: protein, lipid, mineral, fiber, and energy. All laboratory feeding trials will be conducted in a wet lab at Can Tho University.
- Feeding trials on farms will be conducted in AnGiang province of Mekong Delta by CTU researchers.
- Training of women in small-scale farming of snakeheads using formulated feed in the Mekong Delta.
- Survey and processing activities for an increase of added value of cultured snakehead products will be done in An Giang province of Mekong Delta by CTU researchers.

Methods:

This study will comprise interrelated parts:

Study 1. Diet trial to see if soy protein concentrate (SPC) can replace most or all of the FM in diets for snakehead.

Based on results of our previous studies: 40% replacement of fishmeal with soybean meal (SB). We will compare treatments (null hypothesis: no significant difference among treatments), using similar methods to those in effect during the current phase of this project, as follows:

1. 100% FM
2. 40% SB + 60 % Fishmeal
3. 40% SPC +60% Fishmeal
4. 60% SPC +40% Fishmeal
5. 80% SPC +20% Fishmeal
6. 100% SPC

Study 2. Diet trial and bacterial challenge with the best SPC-based diet from the diet trial and immunostimulant products to see if snakehead are more resistant to disease (via bacterial challenges compared to those fish fed FM diets or SPC diets without added immunostimulant).

Study 2.1. Diet trial (null hypothesis: no significant difference among treatments):

1. 100% FM (control)
2. 100% FM + URI immunostimulant
3. 100% FM + commercial immunostimulant
4. Best SPC diet with no immunostimulant
5. Best SPC diet + URI immunostimulant
6. Best SPC diet + commercial immunostimulant

CTU will cooperate with the U.S. Soybean Export Council (USSEC) Vietnam Technical Manager – Aquaculture for research. The laboratory experiments will be conducted in a manner similar to those we conducted previously. Experimental units are 500-L tanks. Although we previously used three replicate tanks per treatment (50 fish per tank), in these trials we will use four replicate tanks per treatment for greater statistical power, especially for the bacterial challenge At the beginning of the experiment, fish (initial weight about 4-5 g) with the same size are weighed, Fish are fed to satiation twice a day and the amount of feed consumed by the fish in each tank is recorded daily by removing and weighing (dry weight) excess feed to ascertain intake. Amounts of food provided per replicate are recorded so that food conversion ratio (FCR) and protein efficiency ratio (PER) can be calculated at the end of the experiment.

The water is maintained at 28±2oC. Any dead fish are recorded and removed daily. Experiments last eight weeks, at the end of which fish are measured and weighed.

Study 2.2. Bacterial Challenge Experiment
This experiment will continue from the 2.2 (diet trial) including the following treatments (null hypothesis: no significant difference among treatments):

1. 100% FM (saline injection)
2. 100% FM (bacterial injection)
3. 100% FM + URI immunostimulant (saline injection)
4. 100% FM + URI immunostimulant (bacterial injection)
5. 100% FM + commercial immunostimulant (saline injection)
6. 100% FM + commercial immunostimulant (bacterial injection)
7. Best SPC diet with no immunostimulant (saline injection)
8. Best SPC diet with no immunostimulant (bacterial injection)
9. Best SPC diet + URI immunostimulant (saline injection)
10. Best SPC diet + URI immunostimulant (bacterial injection)
11. Best SPC diet + commercial immunostimulant (saline injection)
12. Best SPC diet + commercial immunostimulant (bacterial injection)

The bacterial challenge experiment will be conducted at the end of the second feeding trial. These six treatments in trial 2 will divide into 12 treatments, in which each of 6 treatments will be injected with with 0.1 mL of physiological saline (0.85%) as control and each of the rest treatments will be injected with 0.1 mL of bacterial strain *Aeromonas hydrophila* CD1012 based on the lethal dose (LD_{50}) of 1.16×10^5 CFU/mL (Duc *at et*., 2012; Duc *at el.*, 2013). This bacterial challenge experiment will last 2 weeks. During the 14 days post-inoculation, fish will fed their respective diets, and activity and cumulative mortality will be noted daily. For moribund fish, clinical signs will be observed by gross inspection, and lesions will be sampled directly for bacteria. Re-isolation and re-identification of bacteria will be carried out acording to methods of Barrow and Feltham (1993) and the API 20E test kit (BioMerieux) will be used to speciate the re-identified bacterial strains. Blood samples (white blood cell , red blood cell , lysozyme and glucose) of experimental fish will be taken at three different periods including prior to start of experiment, 7 and 14 days post-inoculation. Data from a tank are pooled (i.e., no pseudoreplication) and only one number representing average growth per fish (specific growth rate, SGR) is used per replicate. Economic analysis will be made for both experiments to determine feed cost per kg of fish produced on each diet. Data analysis is by one-way ANOVA, following arc-sine square-root transformation of the proportionate data to insure normality. Tukey's HSD test is used to determine specific differences among means once the ANOVA indicates that significant differences are present. Data from the bacterial challenge test will be subjected to log-rank survival analysis. It is hypothesized that the experiment will find the best level SPC in snakehead diet (based on costs of FM vs. SPC and survival/growth of fish with improved health) optimal diets for use in small-scale snakehead culture.

Study 3. On-farm trials of feeding: Develop the small-scale farming of snakeheads for the women in An Giang province in the flooding season through demonstrations of improvement of feed for a reduction of diseases of cultured snakeheads and economic benefit of women and families. Six small-scale snakehead farms which are owned and operated by women will be selected to develop the small-scale farming of snakeheads using formulated feed. Three of the farms will use hapas (20-50 m^2) and three will use plastic tanks (10-20 m^2). Formulated feed will be made based on the results of the above experiments. Minerals and vitamin C will also be added to the feed to reduce diseases of cultured snakehead. Fish will be stocked at 80 -100 fish/m^2, culture time will be 5-7 month (market size fish). Economic analysis will be made for this trial. It is expected that this feeding trial will improve snakehead culture techniques and income for women

Study 4. CTU researchers will train women in the Mekong Delta in small-scale farming of snakeheads using formulated feed. Specifically, CTU researchers will link with investigation 3 training Cambodian farmers in snakehead culture using formulated feed.

Study 5. Survey and training for an improvement of processed cultured snakehead products for women in An Giang province of Mekong Delta by CTU researchers.

5.1 To conduct a survey of consumers and women fish farmers on the use of major snakehead products (dried and fermented)

5.2 To improve the added value for two major snakehead products (dried and fermented)

5.3 To organize the trainings for women (including women involved in snakehead culture, processing and other activities) on the processing of snakehead products.

Schedule

The duration of implementation of this proposed investigation will be 24 months, starting from 1 October 2013 to 30 September 2015.

Year 1 (10/01/2013 – 09/30/2014):
- First laboratory feeding experiment
- Second laboratory feeding experiment plus bacterial challenge
- Survey of consumption of processed snakehead products
- Development of techniques for conservation and processing of snakehead products

Year 2 (10/01/14 – 09/30/2015):
- On-farm trials of feeding (1 month for weaning of fish to pellets and 6 months for experiment)
- Training of women in the Mekong Delta on small-scale farming of snakeheads using formulated feed
- Training of women on the processing of snakehead products

Deliverables

Publish one peer-reviewed journal per year, plus one fact sheet and two training documentations (one on small-scale farming of snakeheads using formulated feed and one on processing of snakehead products).

ECONOMIC AND ENVIRONMENTAL BENEFITS OF REDUCED FEED INPUTS IN THE POLYCULTURE OF TILAPIA AND MAJOR INDIAN CARPS

Sustainable Feed Technology and Nutrient Input Systems/Experiment/13SFT04NC

Collaborating Institutions and Lead Investigators

North Carolina State University (USA) — Russell Borski

Bangladesh Agricultural University (Bangladesh) — Md. Abdul Wahab, Shahroz Mahean Haque

Objectives

1. Evaluate production parameters and potential economic and environmental benefits of reducing feed inputs by half in tilapia- *Rohu* carp polyculture culture in earthen ponds.
2. Assess the benefit of adding a second major carp, *Catla*, to tilapia-*Rohu* carp polyculture.
3. Evaluate the potential benefits of tilapia - Indian carp polyculture and feed management technology for farms of rural households.

Significance

Pond production of fish constitutes almost 85% of total aquaculture output in Bangladesh, with 60% coming from indigenous Indian major carps, *Catla* (*Catla Catla)* and *Rohu (Labeo rohita)*, and 17% from exotic Chinese carps (DOF, 2010; Belton *et al*., 2011). About 6-7 carp species are cultured together on an *ad hoc* basis, and the fish subsist primarily on primary production (pond fertilization) with occasional feed inputs of rice bran and oil cake. Since carps are omnivores, herbivores, planktivores and/or filter feeders, these fish prefer natural food organisms enhanced by pond fertilization, fish waste and feed inputs (Wahab *et al.,* 2002). When cultured together with other fishes (polyculture), carps enhance dietary household consumption and income earnings through greater production yields and better nutrient efficiency (Azim *et al*., 2004). This constitutes a significant improvement for household dietary nutrition, as 66% of per capita animal protein intake in Bangladesh comes from fish (Hussain 2009; Belton *et al*., 2011).

Tilapia (*Oreochromis niloticus*) was introduced to Bangladesh over 20 years ago and is now one of the fastest growing components of the aquaculture sector, ranking 2nd to carps in total finfish production. Significant works remains to develop better management practices for this cultivar. Current monoculture practices in Bangladesh require significant feed inputs (Dey *et al.* 2008; Belton *et al*. 2011) and high production costs, which limit participation of smaller homestead farmers. This practice also degrades environmental water quality through nutrient loading and pond eutrophication. This investigation seeks to promote better management practices for this industry and greater inclusion by small farms through implementation of a feed reduction strategy, complimented with cheaper fertilizer application (semi-intensive management) thereby reducing the costs constraining participation. Also we will integrate polyculture of major Indian carps with tilapia, providing additional sources of income for farming families throughout Bangladesh and increasing the overall efficiency of the water resources used to grow fish. We anticipate that tilapia-carp farming under reduced feeding will produce greater production yields with less cost, thereby significantly increasing economic profitability for this endeavor. Additionally we anticipate this refined strategy will improve environmental water quality and enhance dietary nutrition for rural farming families: first, by improving income earnings potential, which has been identified as a direct link towards improving household nutrition (FAO, 2012), and secondly by generating a more diverse crop for consumption. Currently, little is known about the production parameters of tilapia cultured with Indian carps, despite widespread appeal for these fish in Bangladesh, however tilapia has been previously cultured with Chinese carps (Abdelghany and Ahmad, 2002; El-Sayed, 2006), and this integrated polyculture produced better yields than for tilapia cultured alone (Khouraiba *et al*., 1991).

In aquaculture, feed is recognized as the dominant cost component of fish farming, representing 50-70% of the total production costs for small-scale, rural farmers (ADB, 2005). Because of this, any reductions in feed can significantly improve the earned incomes for farmers, and reduce negative environmental impacts of fish farming. Further, the promotion of semi-intensive tilapia farming to homesteads practicing extensive farming will be key to enhancing income earning potential, fish consumption and household nutrition in Bangladesh. It is estimated that even modest intensification can improve food security by 4-fold (Dey *et al*. 2008; Delton *et al.*, 2011). Previous CRSP work has demonstrated that tilapia grown with both feed and fertilizer is more efficient than using either input alone (Diana *et al*., 1994). Monocultured tilapia grown under reduced feed rations of up to 50% had little impact on production yields (kg), but improved water quality through reductions in nutrient loading (Diana *et al*., 1994; Lin and Yi, 2003). Further, our CRSP on-farm trials in the Philippines show that reduced-feeding can improve feed conversion rates by up to 100% (Bolivar *et al*. 2010). The present investigation seeks to integrate these strategies with mixed carp polyculture to gain improvements in both tilapia production efficiency and environmental water quality, while also promoting more sustainable, less intensive farming practices.

Quantified Anticipated Benefits

1. We anticipate that declines in feeding ration will improve feed efficiency and reduce costs for growout of tilapia by as much as 35% without compromising yield.
2. Adoption of a combined fertilization and reduced-feeding strategy and addition of carps to the culture of tilapia may increase income returns for farmers by > 20% while providing additional fish (carps) for household consumption or sale at local markets.
3. We anticipate adoption of the reduced feeding strategy and tilapia-carp polyculture will improve environmental water quality and a more sustainable method of fish production.
4. Ten households will receive direct training and benefits on tilapia-carp polyculture and feed management strategies through trials on their farms. These farmers will be actively encouraged to share their findings with others in the community. An additional 100 farmers, extension agents, and stakeholders will receive training through a farmer's day workshop.
5. Two-three graduate/undergraduate students will receive research training and education on sustainable aquaculture technologies.
6. The U.S. is a major importer of Asian grown tilapia. The capacity to grow tilapia on reduced feeding strategies (less nutrient input) with less impact to the environment benefits US businesses and consumers through marketing and consumption of a more sustainable, and environmentally friendly product.

Plan of Work

Location

This investigation consists of three trials. Two will be conducted at the on-station Fisheries Field Laboratory, Bangladesh Agricultural University (BAU), Mymensingh and the third one on various cooperator farms in Bogra in the North Central region of the country. On-farm trials will validate and demonstrate the economic and environmental benefits of the reduced feeding, tilapia-carp polyculture technologies developed from these studies.

Methods

1. Evaluate production parameters and potential economic and environmental benefits of reducing feed inputs with adoption of carp (*Rohu*) into the growout of tilapia in earthen ponds.

This study will address the value of combining feed restriction and fertilization with polyculture of Indian carps into tilapia farming. It will also address if addition of carp under current practices might provide additional environmental and economic benefits to medium and small-scale farmers practicing monoculture. Twelve freshwater ponds (100 m^2) at the BAU's Fisheries Field Laboratory (on-station) will be stocked with sex-reversed Nile tilapia alone or with *Rohu* at an 8:1 ratio as follows:

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Rohu	0	25 (0.625/ m^2)	0	25 (0.625/ m^2)
Tilapia	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)
Fertilization	0	0	4:1 (N: P)	4:1 (N: P)
Feeding	100% Satiation	100% Satiation	50% Satiation	50% Satiation
Replicates (*n*)	4	4	4	4

In the proposed design above, T1 is a control group representing the current practice of tilapia farming. Although ancillary to our primary objective (semi-intensive farming), we also wish to test whether improvements in water quality can be achieved solely through addition of *Rohu* carp (T2). Inclusion of this treatment group also balances our experimental design. Treatment 3 (T3) examines semi-intensive farming of tilapia through a 50% feed restriction/fertilization strategy, and whether growth, production yields, and water quality can be further improved with *Rohu* (T4). Weekly pond fertilization (generally 14% the cost of feed) accompanies the feed reduction treatments (T3, T4) to promote utilization of pond primary production by both tilapia and carp. Ponds will be dried and limed (2 kg $CaCO_3$) and prepared according to standard procedures. Treatment 1 and 2 ponds will be fertilized initially using inorganic fertilizers, urea and triple superphosphate (TSP) at a rate of 28 kg N and 5.6 kg P ha/week (4:1 N:P). Treatment 3 and 4 will be fertilized initially at a rate of 28 kg N and 5.6 kg P ha/week (4:1 N:P) and weekly thereafter at a similar rate. The fertilization levels and rate employed are those that were previously developed by CRSP research activities in numerous countries and encompass those ranges recommended for tilapia culture (Egna and Boyd, 1997; Green and Duke, 2006). Other studies have shown that fertilization every two weeks works as well as weekly at least when using fish at lower densities (see Egna and Boyd, 1997). We will fertilize weekly considering the higher density (5 fish/m^2) used here and to remain consistent with most studies (Egna and Boyd, 1997; El-Sayad 2006; Green and Duke, 2006). We are also incorporating carp, which will likely require additional primary productivity.

Fish will be fed with a pelleted commercial feed (30% CP) as empirically determined every two weeks by the amount of feed consumed over a 15-20 min period. Tilapia will be sub-sampled every two weeks by cast net for growth rate determinations. Based on current feeding practices, satiation rates are likely to begin initially at around 10% bw/day and reduced to ~3% bw/day during the final grow-out. Animals will be fed twice daily at the appropriate daily rate based on treatment groups. After 150 days of grow- out, all fish will be harvested, by seining and complete draining of the pond. The total weight of fish stocks will be recorded at harvest and a subset of fish will be measured for weight and length. Feed conversion ratio (FCR), feed inputs, specific growth rates, and total production biomass will be calculated. A basic marginal cost-return analysis based on input costs (fertilizers/ feed/ fingerlings/ labor) and sales will determine if the reduced feeding-fertilization strategy and/or incorporation of carp can provide cost savings or additional incomes relative to monocultured tilapia provided daily full feeding rates (Bolivar *et al*. 2006). We anticipate based on previous work that 50% reduction in feeding combined with fertilization will prove better than feeding alone at full satiation (Diana et al. 1994; Bolivar et al. 2010). It is anticipated that the incorporation of carps will also provide additional fish yield and profits to tilapia culture.

Standard water quality parameters such as water temperature, dissolved oxygen, pH, total alkalinity, phosphate, total phosphorus, nitrate, nitrite, ammonia, total nitrogen, chlorophyll-a, algae and zooplankton community will be assessed on the spot using meters/sensors as appropriate or at the Water Quality and Pond Dynamics Laboratory at BAU. Most parameters will be measured weekly, and temperature, DO, pH and alkalinity will be measured daily (APHA, 2012). Treatment groups will be tested for significant differences in growth performance, production yields, and water quality using Two-Way Analysis of Variance (feed regimen; addition of carp, interaction effects) followed by Tukey's HSD

test.
Null Hypothesis: No differences in growth efficiency, water quality, or economic returns are observed with tilapia farming under restricted feeding/ fertilization regimen and/or inclusion of Rohu carps.

2. To assess the benefit of addition of a second major carp *Catla* with tilapia-*Rohu* polyculture
This experiment will further refine the reduced-feeding/fertilization and polyculture strategy outlined in Experiment 1 (above). If tilapia under reduced-feeding with carp (T4, Expt. 1) perform less optimally than anticipated, *i.e.* less those produced under full-feeding (T1 or T2, Expt. 1), our technology could be further improved by use of a second Indian carp (*Catla*) alone or in combination with *Rohu*. These two carps encompass discrete niches, *Rohu* feeding primarily on pond algae, while *Catla* are omnivorous, preferring zooplankton, and grow faster than *Rohu*. Therefore greater biomass (production yield) along with further improvements in water quality may be achieved using *Catla* or with a combination of these two carps.

Parameter	Treatment 1	Treatment 2	Treatment 3
Rohu	25 (0.625/m^2)	0	13 (0.32/m^2)
Catla	0	25 (0.625/m^2)	12 (0.31/m^2)
Tilapia	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)
Feeding	50% Satiation	50% Satiation	50% Satiation
Fertilization	4:1 (N: P)	4:1 (N: P)	4:1 (N: P)
Replicates (*n*)	4	4	4

This experiment will test whether the reduced-feeding/fertilization strategy with *Rohu* carp (T1) can be significantly improved by switching to polyculture with *Catla* (T2), or in mixed polyculture with both *Rohu* and *Catla* (T3). Twelve ponds at BAU will be used for this second trial. Fish will be grown out for 150 days. Feeding rates, production parameters, water quality, and cost-return analyses will be assessed as outlined under Study 1.
Null Hypothesis: No significant improvement in growth efficiency, water quality, or economic return is observed for tilapia-Rohu polyculture under reduced feeding, when the carp treatments are modified to include only Catla, or Catla in combination with Rohu.

3. To assess the performance of "Tilapia-Carp Polyculture Technology" on rural farms
The purpose of this on-farm trial is to validate the outcomes of the on-station trials and demonstrate the performance of the new "Tilapia-Carp Technology" to farmers. Two treatments with 10 replications (10 different farms x 2 treatment ponds) will be used for on-farm trial as follows:

Treatment 1: Existing practice of tilapia monoculture using full-ration feeding with commercial diets only.
Treatment 2: Best outcome from the fish polyculture combinations and reduced feed trials from on-station trials in experiment 2.

Ten ponds of nearly similar sizes (100-200 m^2) and approximately similar depths will be selected among 7 cooperators in the Nandigram Upazila of Bogra district. All ponds will be dried and thinly renovated, 8 limed and filled with a nearby underground deep tube well water supply. Then a preparatory dose of inorganic fertilizers urea and TSP will be applied at concentrations described previously. After one week of fertilization fish will be stocked and ponds will be managed according to feeding and stocking strategies identified from experiments 1 and 2. Farmers will be given a data book for recording the feeding and fertilization inputs they use each time. They will be given a two-day short training with a Bengali manual. Women will play a large role in this study as they largely feed and fertilize the ponds as part of household farming activities (Belton *et al*., 2011). BAU staff will monitor the research activities and facilitate the implementation of the trial. Sampling of fish will be made for adjustment of feed inputs. Only basic water quality parameters (temperature, secchi, pH, total alkalinity) will be measured at the on-farm level. Fish will be grown out for 150 days. Production parameters and a cost-return analysis will be assessed as outlined under Study 1.

The tilapia-carp polyculture technology will be disseminated through a day long 'farmers' day' workshop to an estimated 100 farmers, extension agents, NGO representatives, and other stakeholders.

Schedule
July 2013 - November 2013: On-station Trial 1
June 2014 - October 2014: On-station Trial 2
March 2015 - September 2015: On-farm trial, farmers' day event and final report

Deliverables

1. Improvements in On-Farm Profitability – All studies (1-3) will report the estimated market return for each treatment group. The total operating costs for all treatment groups will be collected from the production cycle; including feed, stocking of fingerlings, and labor. On-farm profitability (market return less operating costs) will be reported for all groups. We anticipate a 20-35% increase in profitability.
2. Improvements in Production Yield – Total production yields (kg) and estimated market return will be reported for all groups (see Item 1). We anticipate an improvement (5-10% increase) in total production yield.
3. Improvements in Environmental Water Quality – Water quality parameters will be reported for all ponds and tested for significant differences against the existing practice of tilapia monoculture. We anticipate significant improvements in environmental water quality through efficient feed utilization and mixed carp polyculture.
4. Documentation and Dissemination– The research outlined in Studies 1-2 will be reported through the Technical Reports of the AquaFish Innovation Lab and in the theses and honors-research work of participating graduate and undergraduate students within the Host Country (2-3; BAU). We anticipate, should results be positive, that a publication would result from this work. The findings of Study 3 will demonstrate the effectiveness of this investigation directly to 10 participating farms (~ 2000 m^2 of farming area) within the Host Country. Practicing farmers will be encouraged to share their findings with neighboring families for greater dissemination. Economic profitability and market returns obtained for this study, water quality improvements (from 1-2), and participating farmer testimonials will be reported to the farming community in a "farmers day" event. We anticipate the participation of 100 farmers and other stakeholders (extension fisheries officers, NGOs) at this function.

PULSED FEEDING STRATEGIES TO IMPROVE GROWTH PERFORMANCE, GASTROINTESTINAL NUTRIENT ABSORPTION EFFICIENCY, AND ESTABLISHMENT OF BENEFICIAL GUT FLORA IN TILAPIA POND CULTURE

Sustainable Feed Technology and Nutrient Input Systems/Experiment/13SFT05NC

Collaborating Institutions and Lead Investigators

North Carolina State University (USA)	Russell Borski
Bangladesh Agricultural University (Bangladesh)	Md. Abdul Wahab

Objectives

1. Evaluate the effectiveness of pulsed feeding on tilapia production yields in fertilized ponds.
2. Identify key factors associated with maximal nutrient uptake efficiency, such as amino acid and lipid transporters in the intestine.
3. Characterize changes in gut microbial communities in response to pulse-feeding strategies, and establish whether these changes may be associated with increased nutrient availability.
4. Identify key microbial factors associated with nutrient absorption for potential use as probiotic dietary supplements for enhancing nutrient uptake in fish.

Significance

Global production of farmed Nile tilapia (*Oreochromis niloticus*) has increased exponentially since 1985, with over 2.4 million metric tons consumed in 2010 (FAO, 2013). In Bangladesh, Nile tilapia comprises a significant source of per capita caloric and protein intake, with production increasing 30-fold from 1999-2007 (Gupta *et al*., 1992; Hussain, 2009). Currently, small-scale farmers often use extensive or improved extensive agricultural practices, processes where fertilizer is added (to stimulate pond primary production) but no feeds are used (Belton *et al*., 2011). As the addition of even modest amounts of feed (semi-intensive) can effectively quadruple production, the promotion of semi-intensive farming practices is a key target for increasing personal household income and fish consumption, and greater food security for impoverished farmers in Bangladesh (Belton *et al*., 2011; Dey *et al*., 2008). A significant hurdle for the implementation of semi-intensive farming is the cost of feed, comprising up to 50-70% of total costs. Further, as local feed formulations often have low protein content, farmers compensate by overfeeding their fish, leading to poor water quality (Phillips, 2013; USAID, 2012). We propose to address these issues by demonstrating that equivalent production yields can be achieved with much less feed (50-66% reduction), through the implementation of pulsed feeding strategies, thereby reducing feed and labor costs and making the prospect of switching to semi-intensive culture more attractive to local farmers. Additionally, we will examine how alternate-day feeding strategies may enhance nutrient absorption by measuring nutrient transporter abundance and gut microbial diversity in response to different feeding regimes.

Studies have consistently shown that improvements in dietary nutrition and educational awareness can be achieved through modest increases in household income, particularly so for rural farming communities in developing countries, including Bangladesh (Bairagi, 1980; FAO, 2012). This investigation directly targets the improvement of household income for small-scale tilapia farmers by generating meaningful cost savings in feed. Previously, our CRSP research has shown that Nile tilapia and milkfish (seacages and ponds; *Chanos chanos*) can be grown to market size in monoculture with significant cost savings through implementation of alternate-day feeding over that observed with daily feeding (50% feed reduction; Bolivar et al. 2006; Borski et al., 2011; De Jesus-Ayson and Borski, 2012). Feed conversion was improved by as much as 100% with no loss in production yield. The present investigations will repeat this study in tilapia, in part, to fully reproduce our findings for reliable implementation in Bangladesh and elsewhere, as well as examine further reductions in feed (to 66%, feeding every third day). We will evaluate extensive culture (fertilization only), with those of alternate-feeding (every other day and every third day) with full semi-intensive culture (fertilization + daily feeding) on tilapia growth and production yield to maximize cost-benefits for tilapia farmers. If successful, this refined strategy will be implemented by local Bangladeshi farms to enhance tilapia production efficiency and cost savings, while also mitigating negative environmental impacts associated with nutrient loading.

A better understanding of how finfish acquire and utilize nutrient inputs is requisite for future improvements in aquaculture production efficiency. Part of this investigation seeks to further determine how intestinal nutrient absorption and gut microbial diversity change in response to the use of alternate feeding strategies, which have previously led to dramatic improvements in feed efficiency. Currently, the underlying mechanism explaining how alternate-day (pulsatile) feeding strategies can achieve equivalent production yields with less feed is poorly understood. Some evidence suggests that during periods of fasting, nutrient uptake efficiency in the intestine is intrinsically enhanced, leading to a more-efficient uptake of nutrients at the next feeding period. Thus, fish being fed a daily regime have lower uptake efficiency and do not receive maximal dietary benefit. A similar phenomenon has been postulated, in part, to explain the compensatory growth (CG) response observed in some aquaculture species (Farmanfarmaian and Sun, 1999; Picha *et al*., 2006). Additionally, reduced feeding may promote foraging on primary production within the ponds, leading to a more diverse diet (*e.g.* algae, insect larvae, plankton), which may directly influence intestinal absorption by promoting increases in nutrient transporters not utilized by fish with a constant and predictable diet (Heikkinen *et al.*, 2006; Sigiura *et al.*, 2009). Using the alternate-day feeding experiment, we will evaluate the mRNA expression of key nutrient transporters (involved in protein, lipid, and phosphate uptake) in response to pulsed-feeding strategies. This analysis will further our understanding of how greater nutrient uptake efficiency may be achieved for greater optimization of feeding protocols in the future, generating potential benefits not only for rural farmers in Bangladesh, but could also improve both US and global tilapia farming practices. Testing reduced feeding frequency (every third day) could provide an additional level of cost savings beyond alternate-day feeding, a protocol that could be adapted to studies in Bangladesh and elsewhere.

The emerging field of metagenomics has substantial implications for sustainable aquaculture, as diet, feeding strategy, and other environmental factors strongly influence the diversity and constitutive abundance of intestinal microbiota in both humans and fish (Al-Harbi and Uddin, 2003, 2005; De Filippo *et al*., 2010; Heikkinen *et al*., 2006). In aquacultured finfish, new research has shown that probiotic maintenance of beneficial gut flora can promote growth, greater nutrient availability, and better stock health (Nayak, 2010; Welker and Lim, 2011). Early studies in channel catfish (*Ictalurus punctatus*) and carp (Cyprinidae) identified several limiting nutrients (*e.g*. biotin, pantothenic acid, vitamin B12), which are produced by intestinal microbes, but may be limiting in lesser-quality feeds (Robinson and Luvell, 1978; Kashiwada and Teshima, 1966). In tilapia, the bacterium *Virgibacillus pantothenticus* stimulates intestinal production of alkaline protease, an enzyme involved in the digestion of dietary protein (Thillaimaharani *et al.*, 2012). Naturally occurring lactic acids strains (such as *L. mesenteroides*), appear to inhibit colonization of known fish pathogens (*Vibrio* and *Mycobacterium sp*.) through stimulation of the immune system (Zappata, 2013). Interestingly, proper intestinal flora in tilapia may also positively impact human health as natural flora innoculates could theoretically out-compete non-natural pathogenic microbes. In Nile tilapia (*Oreochromis niloticus*) cultured in Saudi Arabia, fecal coliform bacteria (*E. coli*) comprised up to 10% of gut microbiota, which could be passed on to consumers through improper storage and handling practices (Al-Harbi and Uddin, 2003; Mandal *et al*., 2009). We will test whether the tilapia intestinal microbiome differs in composition with alternate-day feeding, and identify key microbial factors associated with increased nutrient uptake and utilization. Identification of beneficial microbes that improve nutrient uptake will benefit current research into the application of probiotic supplements for the further enhancement of nutrient uptake in finfish cultivars.

Quantified Anticipated Benefits

1. Feed costs could be reduced by 66% by successful implementation of alternate-feeding strategies,

significantly improving economic returns for farming households.
2. Promotion of better tilapia farming practices in Bangladesh will increase household income and fish consumption, thereby contributing to greater food security.
3. Improvement of environmental water quality and fish stock health through better management of nutrient inputs for tilapia pond culture.
4. Identification of key nutrient transporters responsive to changes in alternate-feeding strategies for future optimization of reduced-feeding protocols.
5. Identification of beneficial gut microflora needed for optimal nutritional absorption and generate a greater understanding of how gut microbial diversity changes in response to alternate-feeding strategies. This would allow development of probiotic bacterial supplements for feeds, which may lead to better vitamin synthesis and enhanced nutrient absorption.
6. Two graduate students and one postdoctoral fellow will receive training on sustainable farming practices and genomic technologies enabling aquaculture research.

Plan of Work

Location

These investigations will be performed the Tidewater Aquaculture Facility (Washington, NC) and at North Carolina State University (Raleigh, NC), providing the opportunity to extend advanced genomic capabilities to collaborating institutions within the host country (BAU). All findings from these studies will be shared with Dr. Abdul Wahab and considered for further pond trials in Bangladesh.

Methods

1. The effects of alternate feeding strategies on tilapia growth performance

This aim of this investigation is to identify improved feeding regimens for more efficient tilapia production. This investigation follows previous studies from the Philippines (Bolivar et al. 2006; Borski *et al*., 2011) where a 50% reduction in feeding or feeding a full ration on alternate days resulted in equivalent production yields to fish fed a full ration daily. This study will be reproduced at a domestic production site (US) with additional reductions in feeding (every other day) utilized. Through replication in the U.S. and Philippines (previous CRSP work for alternate day feeding), we will establish whether these pulsed feeding strategies are an ideal strategy that can be universally applied to Bangladesh and other countries. All-male sex reversed Nile tilapia fingerlings (~3 g) will be stocked at 5 fish/m^2 in 16 ponds (0.1ha; 4 replicates per treatment), with weekly pond fertilization at a rate of 28 kg N and 7 kg P/ha/week for all treatment groups. Fish will be fed with formulated feed (28% CP) initially at 10% and then down to 3% body weight/day based on a standard tilapia grow-out schedule. The experimental design is as follows:

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Rohu	0	25 (0.625/ m^2)	0	25 (0.625/ m^2)
Tilapia	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)
Fertilization	0	0	4:1 (N: P)	4:1 (N: P)
Feeding	100% Satiation	100% Satiation	50% Satiation	50% Satiation
Replicates (*n*)	4	4	4	4

Growth parameters (length and weight) will be monitored at 2-week intervals by sub-sampling over a twelve-week growing period. Feed rates will be adjusted accordingly based on this biweekly sampling, and these amounts will be recorded daily. Samples of pond water, tilapia posterior intestine tissue (colon; 1 cm from the anus), and fecal material will be collected for further analysis at NCSU (see Studies 2 and 3). Water quality parameters (*e.g*. nitrates, turbidity, phosphate, dO_2) will be measured as outlined in Investigation 1. The following production parameters will be collected for further economic analysis: specific growth rates (SGR), feed conversion ratio (FCR), total production yield (kg), and total feed

consumption. Production parameters (SGR, FCR, yield) and water quality for all treatments will be tested for significant differences using Analysis of Variance (JMP, SAS industries). A marginal cost-economic return will be performed for all treatments using production yield; labor, feed/fertilizer, and other input costs. Gut retention times will also be examined to evaluate whether alternate feeding strategies alter the intestinal retention of dietary feeds. This component will be addressed during week 12 of the grow-out study, adapting a procedure outlined in Cleveland and Montgomery (2003). Briefly, fish will be fed a single dose of dye-marked (Red 40) pellet feed according to treatment regimen. Fish (n =6) will be sub-sampled by cast nest after feeding, and sampled over time (circuit sampling) until the dye front has moved approximately 1/3rd the distance of the intestine. Tank trials will initially be done to determine the time course over which the dye front moves in the tilapia intestine following feeding. Gut retention time will be tested for significant differences using ANOVA.
Null hypothesis: No significant differences in growth efficiency, economic returns, water quality, or gut retention are observed by use of alternate-feeding strategies for tilapia pond culture.

2. Assessment of tilapia nutrient uptake efficiency in response to alternate feed strategies
This investigation will assess the regulation of nutrient transporters in the gastrointestinal tract of Nile tilapia by feeding strategy for optimization nutrient absorption in the gut. Absorption of nutrients from feed is facilitated through membrane bound transporters located within enterocytes of the gastrointestinal lumen (Broer, 2008; Titus, 1991). We will evaluate how alternate-feeding strategies may change the mRNA expression of key solute-linked nutrient carriers, whose abundance may impact nutrient absorption efficiency (Broer, 2008). From data obtained from the publicly available tilapia genome assembly (http://cichlid.umd.edu), we have identified 6 candidate transporters putatively involved in the digestive transport of amino acids, dietary phosphate (Sugiura, 2009), and lipids across the intestinal epithelium: (1) Na^+-amino acid transporter 2 (*slc38a2*; XP_003455778), (2) Na^+-amino acid transporter 3 (*slc38a3*; XP_003448380), (3) Na^+-amino acid transporter 4 (*slc38a4*; XP_003455755), (4) large neutral amino acid transporter subunit 3 (*slc43a1*; XP_003459747), (5) Na^+-dependent phosphate transporter protein 2A (*slc34a2*; XP_003455260), and (6) long-chain fatty acid transport protein 6 (*slc27a6*; XP_003439516). Samples (n = 6; N = 144) of tilapia intestine (posterior) will be collected from the tilapia alternate feeding study (see Study 1) and analyzed at North Carolina State University. Expressed cDNA will be obtained from these tissues using established procedures (see Picha *et al*., 2006) and mRNA expression of these transporters determined by SYBR quantitative PCR. Significant differences between treatments will be tested by 2-way ANOVA (treatment X time) analysis using JMP (SAS Institute, Cary, NC). This design is chosen specifically over other methodologies (*e.g.* RNAseq) to discern fine-scale changes in the expression of these novel transporters over time and with feeding regimen. *RNAseq* would be cost prohibitive for the treatment X time combinations employed in this study.
Null hypothesis: No significant differences in nutrient transporter mRNA abundance are observed over time or in response to alternate-feeding strategies.

3. Identification of key microbial factors promoting increased nutrient absorption by enterocytes in the tilapia gastrointestinal tract.
This investigation will assess how gut microbial flora is altered by reduced-feeding strategies, and will provide useful data for the identification of beneficial microbes for potential use as probiotic dietary supplements or cultures promoting optimal growth, feeding efficiency, and nutrient utilization in tilapia pond culture. Although performed within the U.S., this investigation can directly improve tilapia-farming practices in Bangladesh through shared transfer of advanced sequencing technology (transcriptomics/ bioinformatics) and through the identification of potential probiotic targets. The establishment of beneficial gut flora to increase nutrient absorption is an emerging research focus in aquaculture science (Welker and Lim, 2011), and may serve to augment existing practices of sustainable feeding for reduction of the environmental footprint. Samples of tilapia fecal material will be collected from the Tidewater/ Pamlico field study (see Study 1) and analyzed at North Carolina State University. Samples will be collected from fish following 0, 6, and 12 weeks of growout, with samples (n=6) pooled together

according to treatment group. We propose the use of a pooled sample design to offset potential variability of microbiota within individuals, instead focusing on common patterns, which may be more reflective of changes with treatment group among the population (pond) as a whole.

Environmental (plasmid/genomic) DNA will be isolated from fecal samples using procedures outlined in Hulcr et al., 2012. Using universal bacteria /archeal primers (Hulcr et al., 2012), the unique region of 16S ribosomal RNA sequence will be amplified for all microbial constituents present within the pooled samples. These amplicons will then be sequenced en masse using next-generation sequencing (Illumina, 30 million reads/lane) followed by large-scale contig analysis, BLAST identification, and hierarchical clustering analysis (UniFrac; Lozupone et al., 2006). We will then test whether gut microbial diversity differs significantly with feeding regime, and identify gut microbes correlating to states of enhanced feed conversion. For each treatment/time combination, a bar-coded amplicon library (n=12) will be constructed and run on 5-7 Illumina lanes (150 bp, single end reads). This design will provide a depth of ~ 17.5 million reads per library. The sequencing and bioinformatic analysis consultation will be performed at the North Carolina State University Genome Sciences Laboratory.
Null hypothesis: No significant differences in microbial abundance or diversity occur with alternate-feeding strategies.

Schedule

May to Sept 2014: Study 1 Growth Trial at Tidewater Aquaculture Research Facility
Sept to Dec 2014: Quantitative analysis of nutrient transporters (Study 2) and water quality evaluated from Study 1. Preparation of microbial 16S rRNA libraries and Illumina sequencing performed (Study 3)
Jan to Aug 2015: Identification of microbial gut populations by metagenomic analysis (Study 3).

Deliverables

1. Improvements in Production Efficiency and On-farm Profitability – The total operating costs will be collected from production (feed/fertilization costs, stocking of fingerlings, and labor costs) and compared to both the crop production yield and estimated market value for all treatment groups (4) outlined in Study 1. We anticipate a 50% or greater savings in feed costs, translating to ~20-35 % increase in on-farm profitability.
2. Improvements in Environmental Water Quality – Water quality parameters will be reported for all ponds used in Study 1 (N=16), and tested for significant differences. We anticipate significant improvements in environmental water quality through use of pulsed feeding strategies that reduce nutrient inputs.
3. Identification of novel mechanisms underlying nutrient uptake efficiency in finfish – Samples collected from Study 1 will be used to identify how pulsed feeding may lead to increases in nutrient uptake through changes in intestinal absorption (Study 2) or through changes in intestinal microbiota (Study 3). Gene expression (fold change) and metagenomic analysis (bacterial identification; hierarchical clustering) will be used to identify key components of enhanced nutrient uptake and utilization in tilapia under reduced-feeding. We anticipate both significant and novel findings from these studies that will be documented in collaboration with the Lead HC P.I. (Dr. Abdul Wahab; BAU).
4. Documentation and Dissemination – the findings from Studies 1-3 will be reported through the Technical Reports of the AquaFish Innovation Lab and the scientific proceedings of the World Aquaculture Society Annual meeting. We anticipate that novel findings arising from the intestinal transporter and metagenomic studies (Studies 2-3) will lead to two high-impact publications within the peer-reviewed literature and will be useful in the development of probiotic supplements. Two graduate students and one postdoctoral fellow will receive training on sustainable aquaculture farming practices, molecular mechanisms of growth in fishes, and genomic technologies enabling aquaculture research.

EVALUATION OF INVERTEBRATES AS PROTEIN SOURCES IN NILE TILAPIA (*OREOCHROMIS NILOTICUS*) DIETS

Sustainable Feed Technology and Nutrient Input Systems/Experiment/13SFT02PU

Collaborating Institutions and Lead Investigators

Sokoine University of Agriculture (Tanzania) — Nazael Madalla, Sebastian W. Chenyambuga

Objectives

The overall objective of this study is to evaluate the suitability of selected invertebrates as protein sources in Nile tilapia (*Oreochromis niloticus*) diets.

The Specific objectives are:

1. To determine the chemical composition of earthworm and maggot meals.
2. To determine the appropriate inclusion levels of earthworm and maggot meal in diets of Nile tilapia cultured in Tanzania
3. To assess growth, feed utilization and cost effectiveness of Nile tilapia diets containing invertebrate as sources of protein

Hypothesis

Growth performance of Nile tilapia (*Oreochromis niloticus*) fed diets containing invertebrate meals is not significantly different from that of those fed diet containing fishmeal.

Significance of the Study

Worldwide aquaculture production has grown significantly with its contribution to global fish supply increasing from 3.9% in 1970 to over 41.3% in 2011 and annual production amounting to 63.7 million metric tonnes valued over USD 119 billion (FAO, 2012). It is now considered as the fastest growing animal producing sector with an average growth rate of 8.8% since 1970 and has outpaced capture fisheries (1.2%) and terrestrial farmed meat production (2.8%) (FAO, 2007). This fast growth has played a key role in augmenting the dwindling catch from capture fisheries in natural water bodies.

Contrary to the global trends, aquaculture production in Africa and Tanzania in particular has remained low, despite the high demand emanating from the fact that fish account for 17.4% of total animal intake; second to Asia (25.7%) (Brummet *et al.,* 2008). In Africa capture fisheries have been exploited to their maximum and in some cases even overexploited. This has resulted in low per capita consumption of 9.1 kg/capita/year compared to global average of 18.4 kg/capita/year (FAO, 2012). African countries import in excess 4.2 million tonnes of fishery products at a net loss of more than three thousand million United State Dollars in order to cope with the demand (Brummet *et al*., 2008).

In Tanzania aquaculture has remained mostly rural, secondary and part-time activity. It mainly involves culture of tilapia and African catfish in small freshwater earthen ponds varying from 150 – 500 m^2 with irregular application of inadequate manure and feeding based on natural food and supplementation with maize bran, kitchen leftovers and green vegetables/weeds. Consequently, productivity is low, about 2,000 kg ha^{-1} yr^{-1} and culture cycle is long taking about 12 months to attain market weight (Machena and Moehl, 2000). Studies have shown that with good quality feeds it is possible to achieve yields of 10,000 kg ha^{-1} yr^{-1} and fish can attain market weight in less than 6 months (Jauncey, 1998). To realized this high yield, pond fish need to be fed with concentrate diets with 30 – 40% protein. For many decades, fishmeal and soybean have been used as the main sources of protein in fish feeds (El-Sayed, 1999; El-Saidy and Gaber, 2002). However, fish farmers in Tanzania are unable to afford good quality protein sources such as fishmeal, soybean meal and other oil cakes that can meet protein requirement required for fast growth and development of fish. Such ingredients are both costly and scarce due to high demand from other livestock sectors as well as human consumption. Attempts to use cheaper alternatives such Moringa and

Leucaena leaf meals have not been much successful due to their relatively low protein content, high fiber content, low digestibility and inherent antinutritional factors (Madalla, 2008; Mbwana 2010; Shigulu, 2012). Hence there is a need to identify and evaluate other protein sources of high quality and affordable to fish farmers.

The nutritive value of fish diet depends on quality of the protein ingredients used in diet formulation. Generally, the feed stuffs of animal origins are considered better alternative protein sources to fishmeal in formulating fish diets because of their higher protein content and the superior indispensable amino acids than that of plant origins. Such sources include invertebrates such as insects, maggots/pupae and earthworms (Omoyinmi and Olaoye, 2012; Mohanta *et al*., 2013). Merits of these protein sources include higher protein content, higher digestibility, local availability and less antinutritional factors. Moreover, these invertebrates are abundantly available and have ability to produce large biomass within a short time because of their short life cycle. Therefore, the current study is aimed at identifying and evaluating commonly available invertebrates for their suitability as protein sources in Nile tilapia (*Oreochromis niloticus*) diets.

Quanitifed Anticipated Benefits

Through this investigation feeding packages based on diets containing commonly available invertebrates as protein sources will be developed and promoted for adoption by small-scale fish farmers. It is expected that through the use of these diets the farmers will improve the productivity of Nile tilapia in their ponds and at the same time reduce the feed cost, thus increase the profitability of fish farming enterprise by selling big sized fish. The increased level of income will improve the purchasing power of the rural farmers for food products, thereby reducing risks of food insecurity at housed levels. Also their per capita consumption of fish will increase, and thus reduce the problem of malnutrition in rural areas.

Impact Indicators

- At least two diets based on invertebrates as sources of protein developed and adopted by small-scale fish farmers.
- Growth rate and body size of tilapia in farmers' ponds will be improved by 50% by the end of the project.
- Income of participating households will be increased by 30% by the end of the project.
- At least one M.Sc. Students will graduate.

Research Design

The study will be an on-station study and a completely randomized design (CRD) will be used to assign dietary treatments to the experimental units.

Location

The study will be conducted at the Aquaculture Research Farm of Sokoine University of Agriculture in Morogoro, Tanzania.

Methods

The following activities will be undertaken to achieve the stated objectives.

Activity 1: Collection and culturing of Invertebrates with Potential for Use in Aquafeeds

Two invertebrates; earthworms (*Eudrilus eugeniale*) and maggots (*Musca domestica*) will be used as protein sources in Nile tilapia diets. Earthworms will be collected and cultured on mixtures of sand, cattle dung and saw dusts while maggots will be cultured on the mixture pig dung, pig hairs, chicken droppings and feathers in order to generate large quantities.

Activity 2: Biochemical Analysis of Selected Invertebrates
Proximate analysis (moisture, crude protein, crude lipid, crude fiber, ash and nitrogen-free extracts) will be performed according to standard methods (AOAC, 1990). Samples of fishmeal, earthworm meal and maggot meal will be analyzed for amino acid (Antoine *et al*., 1999) and fatty acid (Teng and Made Gowda, 1993) profiles using the HPLC method.

Activity 3: Growth Trials to Evaluate the Effects of Invertebrate Meal on Growth Performance of Nile Tilapia
Two growth trials will be undertaken as follows:
Sub – Activity 3.1 Short term growth Trials
The trial will be undertaken for a period of 60 days to determine optimum inclusion levels of earthworm and maggot meals in the diets of Nile tilapia. Ten diets will be formulated to evaluate the effects of replacing fishmeal with earthworm and maggot meals. Other ingredients that will be used to formulate the diets are hominy meal, wheat flour, vitamin premix and mineral premix. Diet 1 will serve as a control diet and it will be based on fish as the sole source of protein. Diet 2, Diet 3 and Diet 4 will be based on earthworm meal, maggot meal and mixture of moringa meal and sunflower seed cake as the only sources of protein in the diets, respectively. In diet 5, diet 6 and diet 7 fishmeal will be replaced by 50% with earthworm meal, maggot meal and mixture of moringa meal and sunflower seed cake, respectively. In diet 8, diet 9 and diet 10 fishmeal will be replaced by 75% with earthworm meal, maggot meal and mixture of moringa meal and sunflower seed cake, respectively. All diets will be formulated to contain 30% crude protein and 10% crude lipid. Each of the dietary treatment will be assigned randomly to experimental units and replicated three times. The experimental units will be comprised of buckets with capacity of 30 liter connected to a recirculation system. Ten 10 Nile tilapia fingerlings of approximately 3 - 5 g will be cultured in each bucket. The fish will be fed the respective experimental diets to apparent satiation. Body weight and feed intake will be determined on weekly basis. Growth performance and feed utilization will be determined using the following parameters: Average Daily Weight Gain, Specific Growth Rate, Feed Conversion Ratio, Protein Efficiency Ratio, Protein Productive Value. In addition, whole body composition of fish samples will be determined using proximate analysis scheme before and after the experiment.

Sub – Activity 3.2 Long term growth Trial
The best diets (based on earthworm and maggot meals as sources of protein) from the short-term trial will be used in the long-term growth trial to ascertain the benefits of using those diets in comparison to the fishmeal as protein sources. All the diets will be formulated to contain 30% protein and 10% lipid and the fish will be fed at 5% of their body for a period of 180 days. Fish will be stocked at a density of $3/m^2$ in outdoor concrete tanks with capacity of $4.5\ m^2$. Growth, feed utilization as well as cost effectiveness will be determined. Cost effectiveness will be determined through gross margin analysis and feed cost to produce a kilogram of fish. In both trials, water quality parameters such as oxygen, pH, total ammonia nitrogen and nitrate will be monitored to ensure that they are within acceptable limits.

Activity 4: Data Analysis
One way ANOVA will be used to analyze the data to test the effects of the diets on body weight gain, growth rate, feed conversion ratio and Protein Efficiency Ratio. Initial body weight of the fish will be used as a covariate to adjust the variation in initial body weight. Where significant difference in treatment means exist the LSD test will be applied to establish which means are actually significantly different.

Deliverables

- Outputs will include reports and peer-reviewed publications that will be made available to policy makers. These will be available online and in print.
- A workshop will be offered to stakeholders to present findings from the study.Findings from the investigation will be presented at regional and international professional conferences.

Schedule (1 July 2013 – 30 September 2015)

Activities	**2013/2014**				**2014/2015**			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Objective 1: To determine the chemical composition of earthworm and maggot meals								
Activity 1.1: *Collection and culturing of Invertebrates with Potential for Use in Aquafeeds*	■							
Activity 1.2: *Biochemical Analysis of Selected Invertebrates*	■	■						
Activity 1.3: *Data analysis and report writing discussion*			■					
Objective 2: To determine the appropriate inclusion levels of earthworm and maggot meal in diets of Nile tilapia cultured in Tanzania								
Activity 2.1: Conduct short-term feeding trials for 60 days				■				
Activity 2.2: Data analysis and report writing					■			
Objective 3: To assess growth, feed utilization and cost effectiveness of Nile tilapia diets containing invertebrate as sources of protein								
Activity 3.1: Conduct long-term feeding trial for 180 days					■	■	■	
Activity 3.2: Data analysis and report writing survey							■	
Final Report Writing								■

ENHANCING THE NUTRITIONAL VALUE OF TILAPIA FOR HUMAN HEALTH

Sustainable Feed Technology and Nutrient Input Systems/Experiment/13SFT02PU

Collaborating Institutions and Lead Investigators

Kwame Nkrumah University of Science and Technology (Ghana)	Nelson W. Agbo Regina Edziyie
University of Arkansas at Pine Bluff (USA)	Rebecca Lochman

Objectives

1. Assess the availability and distribution of potential fish feed ingredients containing n-3 fatty acids for use in Nile tilapia diets in Ghana.
2. Determine the proximate composition and fatty acid composition of potential feed ingredients, and recommend specific inclusion rates for diets to be tested in feeding trials with Nile tilapia in Ghana.
3. Analyze the proximate and fatty acid composition of experimental diets and fish from feeding trials in Ghana and determine cost-of-gain of the different diets.
4. Determine the amount of tilapia that would need to be consumed by humans to obtain the target amount of n-3 fatty acids (500-1500 mg/day) for health benefits.

The null hypothesis for the feeding trial is that there will be no difference in n-3 fatty acid content among fish fed diets with different ingredients.

Significance

Data on food intake in Ghana and other developing countries suggests that many people do not get enough essential fatty acids. Both n-3 and n-6 fatty acids are essential nutrients for people, but there is a striking imbalance in the intake of n-3 and n-6 fatty acids in the US and many developing countries. Intake of n-6 fats far exceeds that of n-3 fats due to the widespread use of plant oils and grains that contain more n-6 than n-3 fatty acids (Trushenski and Lochmann 2009). Thus, traditional diets can lead to marginal to severe deficiencies of n-3 fatty acids and a variety of associated health problems such as cardiovascular disease, arthritis, atherosclerosis, diabetes, and cancer (Horrocks and Yeo 1999; Arterburn et al. 2006; Simopoulos 2008). In infants, the n-3 fatty acids are crucial for normal brain development, behavior and cognitive ability.

In Ghana, n-3 deficiency is more common in infants and pregnant or lactating women than in adult males (Siekmann and Huffman 2011). Deficiency of n-3 fatty acids during infancy can be especially destructive, as fatty acids such as DHA are crucial for normal brain development and cognitive function (Innis 2007).

Fish are the primary practical source of n-3 fatty acids in most countries (Tocher 2003), and fish supplies approximately 60% of the protein for the population of Ghana. However, farm-raised fish that are fed diets high in n-6 fatty acids will accumulate high levels of n-6 fatty acids in their tissues. Farmed tilapia have received criticism for being too high in n-6 and too low in n-3 fatty acids (Weaver et al. 2008). This is a function of their diets, which typically contain large amounts of plant ingredients high in n-6 fatty acids. Although these ingredients are considered environmentally sustainable to use in fish diets, they lack the healthy n-3 LC-PUFA that are found in marine fish products. There is a tuna processing plant in Tema, Ghana that provides some fishmeal for tilapia diets. However, catches of tuna are declining and it would be preferable to identify viable plant sources of n-3 fatty acids for long-term growth and sustainability of the aquaculture industry in Ghana. Fortunately, tilapia can elongate and desaturate 18:3n-3 found in plant oils to form n-3 LC-PUFAs such as 20:5n-3 and 22:6n-3. Therefore, inclusion of preformed LC-PUFAs is not necessary for the general performance or health of the fish (NRC 2011).

It is well known that fish acquire the fatty acid signatures of their diets (they "are what they eat")(Turchini et al. 2011). The degree of enrichment and the time needed to achieve a target level of enrichment will depend on the amount of n-3 fatty acids in the diet, the feeding rate, and length of time the fish are fed the diets. The diets will also need to support optimal growth, feed conversion and survival of the tilapia to minimize cost-of-gain and support production profitability. In this project, we will identify and characterize locally available, cost-effective ingredients that will add n-3 fatty acids to the diets of tilapia, and create an n-3 enhanced product that is a preferred fish to Ghanians but has greater potential to enhance their health.

The potential health impact can be assessed by comparing the concentration of n-3 fatty acids in the fish to the daily recommended intake of n-3 fatty acids for good health in humans from medical and health organizations such as the American Heart Association and the World Health Organization. Currently, the recommended range is from 500-1500 mg/day depending on factors such as age, gender, reproductive status, and prior history of coronary problems. The number of servings of fish with a given concentration of n-3 fatty acids that would need to be consumed to improve health status can then be calculated. This metric is easy for the layperson to understand and can be included in health education materials such as pamphlets and bulletins.

The suitability of feed ingredients for commercial production of both fish and feed are based not only on nutrient content, but on economics and availability, as well as palatability to the fish (Hardy and Barrows 2002). In Ghana, a large number of oilseed and cereal by-products are available for screening as potential sources of n-3 fatty acids for fish feeds (Nelson and Wallace, 1998; Hecht, 2007). A few plants found in Ghana such as *Leucaena leucocephala* and *Moringa oleifera* contain more than 30% 18:3n-3 in their lipids. There is some information on the feeding value of *Leucaena* and *Moringa* in Nile tilapia (Adeparusi and Agbede 2005; Madalla 2008), but more information is needed to optimize the inclusion levels of these leaf meals in diets to obtain both profitable production and improved product quality (i.e., enhanced content of n-3 fatty acids). A recent study at the University of Arkansas at Pine Bluff (Kasiga 2012) showed that leaf meals made from these plants could be substituted for up to 30% of the protein in soybean meal in diets of Nile tilapia without reducing fish performance. The leaf-meal diets also significantly increased the concentration of total n-3 fatty acids and n-3 LC-PUFAS in the fish. These preliminary results should be expanded to include other variables. For example, the basal diet included some fish oil because the primary focus of the study was on use of the leaf meals as protein sources. It would be preferable to test the leaf meals in diets without any fishmeal or oil in line with the global trend toward fishmeal and oil reduction in aquafeeds. Also, Kasiga (2012) did not grow the fish to market size, so diets containing these leaf meals need to be tested in fish for a full growing season, and the fatty acid composition and taste of the market-size fish should also be assessed. In addition to the leaf meals, a survey should be conducted to identify any other potential feed ingredients available in Ghana that would enhance the n-3 fatty acid content of the fish and meet the other criteria discussed previously.

Aside from whole plant ingredients, it is possible to add isolated lipid sources to the diets also, such as flaxseed oil. This oil contains more than 50% 18:3n-3, and does not inhibit tilapia growth (Karapanagiotidis et al. 2007). There is a commercial producer of flaxseed oil in Cameroon, which currently sells the oil for $350/MT. This might be close enough for Ghana to consider using it in tilapia diets. It is also possible to maximize the retention of the desirable n-3 LC-PUFAs in fish by supplying most of their dietary fat as saturated fat such as coconut oil or palm kernel oil (Trushenski et al. 2009). These oils are widely available in tropical regions and could be used in combination with an n-3 lipid like flaxseed oil to optimize the n-3 content of the fish while keeping diet cost as low as possible. This strategy has not been tested in tilapia using diets without fishmeal and oil, so further verification of the strategy using diets without marine products is needed.

In summary, the ability to produce tilapia enriched with n-3 acids as a functional food could be a key factor in mitigating widespread health problems associated with essential fatty acid deficiencies in Ghana and other developing countries. The challenge is to identify n-3 sources that will support fish performance and enhance the quality of farmed tilapia for human health while maintaining production profitability.

Quantified Anticipated Benefits

The study will produce information useful for practical diet development for Nile tilapia in Ghana that will result in production of a fish with a healthier lipid profile (enriched in n-3 fatty acids) compared to conventionally grown fish. The number of servings of fish needed to provide the recommended daily intake of n-3 fatty acids for health benefits will be calculated for each diet. The study will also emphasize the importance of using environmentally sustainable and cost-effective ingredients to accomplish the nutrient enhancement of tilapia.

Production of healthier tilapia is part of a larger strategy to improve the nutritional status of people in developing countries such as Ghana. The information will be summarized in lay publications suitable for distribution at workshops or posting on websites. The information will also be prepared for publication in peer-reviewed journals.

Quantifiable

The number of suitable ingredients identified and characterized in the survey as having good potential to enhance n-3 fatty acids in tilapia (target = 5 minimum); number of lay publications produced (at least one); number of journal articles produced (at least one).

Deliverables

At least one fact sheet or article for posting on website (for the layperson or farmer); at least one journal article (in Journal of Applied Aquaculture or other suitable peer-reviewed journal).

Research Design/Activity Plan

Location

This study will be conducted in Ashanti and Brong Ahafo regions of Ghana and the feed trial in the FRNR facilities in the KNUST. UAPB will assist in the survey to identify new feed ingredients, and will analyze the proximate composition and fatty acid composition of the ingredients. Following analysis, UAPB will advise HC personnel on inclusion levels of the most promising ingredients to include in feeding trials. After diet formulation at KNUST, UAPB will also analyze the proximate and fatty acid composition of the finished diets. Following each feeding trial, UAPB will analyze samples of fish for proximate and fatty acid composition.

Methods

Feeding trials (KNUST): One feeding trial will be conducted in year 2, and another in year 3. Both trials will be conducted in hapas placed in earthen ponds at the KNUST aquaculture facility in Kumasi (Ashanti region). Based on the composition of potential feed ingredients from UAPB, the 2-3 most promising ones will be selected for the first feeding trial (Year 2). Experimental diets will be formulated by substituting the appropriate amounts of the new ingredients for traditional ingredients with the goal of increasing the total n-3 content of the diets. Diets will be formulated to meet or exceed the known nutrient requirements of Nile tilapia (NRC 2011) and will be as similar as possible in total protein and energy content. The control diet will be a locally produced tilapia feed (Raanan Feeds). Proximate and fatty acid analysis of five fish will be conducted before the experiment begins (baseline data), and at the end of each experiment to test for differences in composition due to diet. Ten-gram fish will be stocked at 30/hapa (1m X 1m X 1m), and each treatment will have four replicates. Fish will be fed 4-6% body weight daily (based on fish size). Water quality will be monitored throughout the feeding trials. Dissolved oxygen, temperature and pH (5-7 days a week), nitrite, total ammonia, and chlorophyll a will be determined weekly. At two-week intervals during each trial 15 fish from each hapa will be randomly selected and weighed to track growth. Trial 1 will last 8-12 weeks. At the end of the trial all fish will be counted and weighed. Weight gain, survival and feed conversion will be analyzing using 1-way ANOVA and differences in means will be considered significant at $P<0.05$. Specific differences in means will be identified using Fisher's LSD test. Based on the results of the first feeding trial, new diets will be formulated to refine the results in the second feeding trial (year 3), which will last 6 months or until fish achieve market size. A very basic consumer taste test will be run at the end of the second trial to assess acceptability on the market. However, in Ghana fish size is more important than taste.

Proximate and fatty acid analysis (UAPB): Dry matter and ash will be determined by drying the sample at 135°C for 2 h, and burning the sample at 600°C for 3 h, respectively (AOAC 1995). Crude fiber (of feed ingredients and diets only) will be determined according to Ankom filter bag technique (AOCS 2005; Ankom 200 fiber analyzer, Ankom Technology Corp., Fairport, New York). Crude protein will be analyzed with the Macro-Kjeldahl method of total nitrogen analysis and the protein content in samples determined by multiplying the nitrogen values by 6.25. Total lipid will be determined using chloroform/methanol (Folch et al. 1957). The nitrogen free extract (NFE), a measure of soluble carbohydrates, will be calculated by subtracting the percentage protein, lipid, ash, fiber and moisture from 100. Lipid extracts from the diet ingredients, diets and fish will be used for fatty acid analysis. Ten mL of the lipid extracts will be evaporated under nitrogen and then trans-esterified with 14% boron trifluoride. The resulting fatty acid methyl esters (FAMEs) will be analyzed (Morrison and Smith 1964) using a flame ionization gas chromatograph with helium as the carrier gas. The FAMEs will be separated on a fused silica capillary column (15 m x 0.25 mm internal diameter). The injection volume will be 1µl, with an injector and detector temperature of 250°C and 315°C, respectively. The column temperature will be held initially at 100°C for 10 min, increased to 160°C at a rate of 15°C/min and held for 4 min, then increased to 250°C at a rate of 2.5°C/min. The FAMEs will be identified and quantified by comparing the retention time and peak area to those of serially diluted mixtures of reference standards. After the feeding trials and all analyses, the cost-of-gain will be calculated by determining the cost of the amount of feed (kg) required to produce 1 kg of tilapia. The costs of the diets and feed conversion data will be used to generate cost-of-gain. Based on the total n-3 composition of the fish, the amount of fish that would have to be consumed to provide the recommended daily intake of n-3 fatty acids for human health will also be quantified.

Schedule

Start date: The study will begin July 1, 2013, and end September 30, 2015.

Anticipated timetable

July 1 - December 31, 2013 - conduct survey, obtain feed ingredients, and analyze their proximate and fatty acid composition (KNUST - obtain and send feed ingredients; UAPB - lab analysis of ingredients.)

January 1 - December 31, 2014 - Formulate diets (UAPB and KNUST) and conduct initial feeding trials with tilapia at KNUST. Send feed and fish samples to UAPB for analysis. Formulate diets for second feeding trial (UAPB and KNUST).

January 1 - September 30, 2015 - Conduct second feeding trial (KNUST). Send feed and fish samples to UAPB for analysis. Analyze results statistically and prepare them for presentation and publication.

PRODUCTION OF PERIPHYTON TO ENHANCE YIELD IN POLYCULTURE PONDS WITH CARPS AND SMALL INDIGENOUS SPECIES

Sustainable Feed Technology and Nutrient Input Systems/Experiment/13MER06UM

Collaborating Institutions and Lead Investigators

University of Michigan (USA)	James Diana
Agriculture and Forestry University (Nepal)	Madhav Shrestha
	Sunila Rai

Objectives

1. To compare growth and yield of carps between carps and carp-SIS polyculture systems;
2. To compare growth and yield of carps and SIS with and without periphyton enhancement;
3. To compare profitability among the different polyculture systems; and
4. To assess water quality in different systems.

Significance

The government of Nepal (GoN) has recognized that chronic malnutrition is a major problem in the country. The most common forms of malnutrition include undernutrition (insufficient energy), and deficiencies of vitamins and minerals, particularly vitamin A, iodine, and iron. About 41% of children less than five years of age are stunted (UNICEF, 2012a) and, 48% are anemic (MoHP, 2006). Also, 36% of women age 15-49 are anemic (MoHP, 2006). Realizing this, Baburam Bhattarai, Past Prime Minister of Nepal, made a strong commitment to improve the nutritional status of children and women for future socio-economic growth and development of the country. To ratify the commitment, the GoN signed the Declaration of Commitment for Accelerated Improvement in Maternal and Child Nutrition, and launched the Multi-Sectoral Nutrition Plan (MSNP) on 17 September 2012 (UNICEF, 2012b).

With the current nutrition problem, there is a need to develop environmentally sustainable and cost-effective food production systems that function year-round to provide adequate nutrients and improve household income for rural poor farmers. Since 2008, the Institute of Agriculture and Animal Science (now the AFU) has promoted an innovative and environmentally sustainable fish production system of "Carp-SIS polyculture" to improve nutrition of poor women and children in Terai (Rai, 2012, 2013). The approach includes increased intake of nutrient-rich, small indigenous fish species (SIS) to improve health and nutrition of women and children. Vitamin A, calcium, zinc, and iron are found to be much higher in the eyes, head, organs, and viscera of SIS (Roos et al., 2006). Since SIS are eaten whole, there is no loss of nutrients from cleaning or as plate waste. Moreover, SIS are self-recruiting in aquaculture ponds after initial stocking, and can be harvested weekly and biweekly, favoring regular household consumption. A carp-SIS polyculture system also provides additional income through the sale of surplus fish. Carp polyculture is a commercial scale aquaculture system managed mainly by men for market sales. Studies revealed that addition of SIS to this farming system raised fish production above that of the national average, doubled consumption rate of household members, and provided Rs. 3,025 income per household in 270 days, which helped the family to be empowered economically (Rai, 2012).

Adding substrates such as bamboo to carp-SIS ponds can increase carp production and household income. As periphyton removes nutrients from the water and adds oxygen, it also cleans up water being discharged from ponds and improves environmental performance. Since rohu, catla, and common carp are periphyton feeders (Rai and Yi, 2012), their growth and production are enhanced in ponds with added substrate for periphyton colonization compared to ponds without substrate (Azim et al., 2002; Rai et al., 2008). Azim et al. (2001) showed a 70% increase in rohu production in ponds with substrates for periphyton, compared to control ponds. However, gonia (*Labeo gonia*) had no increase in growth, indicating that the effect of periphyton enhancement was species specific. Azim et al. (2004) showed a

59% increase in net yield for polyculture carp ponds with feed and periphyton enhancement, and a 28% increase in yield for periphyton enhancement only, compared to ponds with fertilizer only. However, yields in on-station trials were 77% higher than on-farm trials, indicating that more work was needed to understand and enhance farm management to achieve desired yields in periphyton-enhanced production. However, in spite of this difference, they also found that periphyton enhancement was economically viable for improved production.

The economic value of periphyton enhancement includes the ability to grow fish faster under similar inputs, as well as the ability to reduce inputs of feed and achieve similar growth rates. Since the combination of species, type of feed, and other characteristics would influence the yield and income produced in such a system, it is necessary to test the full combination of feed inputs, periphyton enhancement, and production to truly understand the best system to use for commercial production (Diana, 2012). Therefore, we will compare production among systems with: no SIS, no periphyton, and normal feeding (control); SIS and normal feeding; periphyton enhancement, SIS, and reduced feeding; and SIS, periphyton enhancement, and no feeding. This should give a reasonable indication of the full potential for changes in cost-benefit ratio considering inputs of fish, fertilizer, and feed.

The study is intended to compare fish production between normal carp-SIS polyculture and periphyton-enhanced carp-SIS polyculture in order to develop a cost-effective means to increase fish production. Since on-farm trials have shown significant reductions in production compared to on-station trials, we will also evaluate performance differences between farm and station systems.

Quantified Anticipated Benefits

The results of this study will develop a more sustainable carp-SIS polyculture system suitable to small-scale farmers in Nepal. We anticipate that the polyculture system with periphyton will increase on-farm fish yield by at least 20%, which should improve family income and also increase household fish consumption, particularly that of SIS. This will be quantified by evaluation of on-farm trials in 20 ponds. This technology will benefit farmers through improved family nutrition, health, and livelihood. In addition, famers will have the opportunity to harvest and consume SIS from their ponds for year-round consumption because in carp-SIS production, system ponds are not completely drained during final harvest. Since SIS grow well in shallow water, they can be produced in the dry period when carp polyculture is not feasible. We will document harvest and yield of SIS from the 40 farms over an entire year to estimate the household consumption benefits of SIS production. On-farm trials are planned for 20 farms in each location, so that at least 40 farmers will be exposed to these new combinations to try in their household ponds.

Deliverables

One report documenting yield improvements from polyculture – SIS – periphyton culture. Outreach of methodology to 40 farmers through on-farm training, and to 40 additional farmers through a workshop.

Research Design

This experiment will evaluate increased yield of carps and SIS as a result of enhancing periphyton production, and will also determine improvements in water quality as a result of periphyton treatments.

Location

- First an on-station trial will be done at AFU, then on-farm verification of the best system will be tested in farmers' ponds in two districts; at Majhui, Chitwan and Kawasoti, Nawalparasi.

Methods

- AFU Pond Research
- Pond facility: 12 earthen ponds of 150 m^2 will be used for on-station trials
- Culture period: 6 months each for on-station and on-farm trials, SIS monitored for 12 months.

- Test species: carps (common, silver, bighead/catla, grass, rohu, mrigal) and SIS (dedhuwa and pothi)
- Stocking and treatments
- Stocking size: carps (5-10 g), SIS (2-5 g)

On-station Trial

- The on station trial will include 4 treatments with 3 replicate ponds each:
- Carp polyculture (15000/ha) with normal supplemental feeding (control)
- Control + SIS (50000/ha) with normal feeding
- Control + SIS (50000/ha) + bamboo substrate (covering 1% of pond surface area) with 50% reduced feeding
- Control + SIS (50000/ha) + bamboo substrate (covering 1% of pond surface area) with no feeding

On-farm Verification

The best two carp-SIS polyculture systems obtained from the on-station trial will be verified in two districts, Chitwan and Nawalparasi, covering 20 household ponds in each district. Overall production levels and SIS yield will be evaluated for each farm by record keeping during harvest.

- Nutrient input: Fertilization and daily feeding 6 days per week with dough of rice bran and mustard oil cake at 2% BW for most carps and grass to grass carp at 5% BW.
- Water management: maintain at 1 m deep.
- Sampling schedule (on station trials): Water quality: Biweekly water sampling, Standard CRSP protocol. Fish growth: monthly sampling of carps only. Partial harvesting: Monthly after first breeding of brood SIS, continued over a full year. Periphyton production will be monitored monthly using growth on 10 x 10 cm ceramic tiles.

Statistical design, null hypothesis, statistical analysis (on station trials)

- Statistical design: Completely randomized design (CRD)
- Statistical analysis: Multiple ANOVA
- Null hypothesis: There are no differences in growth, production, gross profit margin, and partial harvest among different polyculture systems (control, with SIS, with SIS and periphyton, with SIS, periphyton and no feeding). There are no differences in water quality among the different polyculture treatments.

<u>Schedule</u>

AFU experiment will begin 1 March 2014 and run 180 days; the report will be submitted no later than March 2015. On-farm trials will begin 1 March 2015 with final report no later than 30 September 2015. SIS production in both trials will be monitored for a full year.

TOPIC AREA

CLIMATE CHANGE ADAPTATION: INDIGENOUS SPECIES DEVELOPMENT

❖

TWO SMALL INDIGENOUS SPECIES TO IMPROVE SUSTAINABILITY IN TYPICAL POLYCULTURE SYSTEMS IN NEPAL

Climate Change Adaptation: Indigenous Species Development/Experiment/13IND06UM

Collaborating Institutions and Lead Investigators

University of Michigan (USA)	James S. Diana
	Bailey Keeler
Agriculture and Forestry University (Nepal)	Madhav K. Shrestha
	Naryan P. Pandit
	Ram B. Mandal

Objectives

1. To evaluate the impact of adding different densities of two small indigenous fish species (Punti *Puntius sophore* and Deduwa *Esomus danricus*) to the yield and economic performance of the 6-species carp polyculture system in Nepal; and
2. To determine the impacts of adding new species on water quality and primary production in polyculture ponds.

Significance

Carp polyculture is the most common aquaculture system in Nepal and dominates total production. Pond owners and managers are typically male, and most fish harvested are used for market sales; thus, they do not enter largely into household consumption. However, intentional inclusion of small indigenous species into polyculture has been suggested to help these systems contribute to household consumption and nutrition. The intake of nutrient-rich SIS should improve the health and nutrition of women and children. Vitamin A, calcium, zinc, and iron are found to be much higher in the eyes, head, organs, and viscera of SIS (Roos et al., 2007). SIS have a faster reproductive rate than carp species commonly breed in culture ponds (Kadir et al., 2006). They can therefore be harvested throughout the grow-out season, adding consistently to household consumption, even during times of low water levels. A carp-SIS polyculture system also provides income through the sale of surplus carp. This farming system raised fish production above that of the national average, doubled consumption rate of household members, and provided Rs. 3,025 income per household in 270 days, which helped families to be empowered economically (Rai, 2012). Adding substrates such as bamboo to carp-SIS ponds can increase carp production and household income. Since rohu, catla, and common carp are periphyton feeders (Rai and Yi, 2012), their growth and production are enhanced in ponds with added substrate for periphyton colonization compared to ponds without substrate (Azim et al., 2002; Rai et al., 2008). Similar results have been found in Bangladesh as well (Wahab et al., 2003).

While SIS have been added to polyculture ponds and the results to date seem favorable, there has been little experimentation on the density of SIS to use in establishing a breeding population and the resulting production of SIS from these ponds for household consumption. Once introduced to the pond, most species of SIS will naturally breed there and self-recruit to the population. Therefore, the density of SIS needed to induce full breeding and recruitment is an important criterion to the enhancement of production that they can induce. This project will expand on our research incorporating SIS by exploring the feasibility of adding SIS at different densities to a typical culture system in Nepal.

Periphyton has been shown to increase production of various carp species (Azim, et al. 2001; 2002). Earlier experiments (Investigation 2) were designed to test the importance of substrates to production of periphyton and fish in polyculture ponds. In support of that study, we will use bamboo substrates in this experiment to allow this enhanced periphyton production, and test the stocking ratios of SIS. This study will compare SIS production in polyculture ponds under different stocking densities to allow more consistent production of SIS in ponds. It will also use periphyton as a means to increase production and improve water quality.

Quantified Anticipated Benefits

The target end users of this system are small-scale rural farmers and their families in the Terai region of Nepal. We anticipate that the addition of SIS to this culture system will increase yield by at least 20%, without reducing carp production. We will document increased production by monitoring the pond production system. The large carp species are commonly considered cash crops and are sold in local markets as well as consumed in the home. SIS would serve principally as a regular food source for farmers. SIS addition to large carp culture will directly improve the nutritional options for farmers and their families. We believe that SIS produced in the ponds will increase household fish consumption by women and children by at least two-fold. We will complete surveys of household consumption to document the consumption benefits of SIS production.

Deliverables

Increase farm production through SIS incorporation, documented by a report on experimental results. Improve household consumption via SIS production in ponds, documented by household surveys. Overall benefits will be developed into a fact sheet for further extension.

Research Design

Location

- The ponds will be located in the Chitwan region of Nepal and will be earthen experimental ponds in Kathar. The farms will be owned by local residents, but managed by the research group. Farm families will derive the benefit of SIS consumption and carp sales.

Methods

Pond Research

- Pond facility: 12 earthen ponds of 100 m^2 will be used
- Culture period: 6 months; SIS monitored for 12 months.
- Test species: Carps (common, silver, bighead/catla, grass, rohu, mrigal) and SIS (dedhuwa and pothi)

Stocking and treatments

- Stocking size: Carps (5-10 g; stocked at 15,000/ha), SIS (2-5 g)
- Carp polyculture alone (control) with normal feeding and periphyton enhancement,
- Control + SIS (25,000/ha),
- Control + SIS (50,000/ha),and
- Control + SIS (100,000/ha).

Nutrient input: Fertilization and daily feeding 6 days per week with dough of rice bran and mustard oil cake at 2% BW for most carp and grass to grass carp at 5% BW. Bamboo stakes will be used as additional substrate in all treatments in order to promote periphyton colonization.

- Water management: maintain at 1 m deep.

Sampling schedule: Water quality: monthly water sampling, Standard CRSP protocol. Fish growth: monthly sampling of carps only. Partial harvesting: Monthly after first breeding of SIS, remove one seine haul of SIS per week. Weight of SIS harvested will be recorded. Periphyton production will be monitored monthly using growth on 10 x 10 cm ceramic tiles. Partial enterprise budgets will be constructed from inputs and yield of each experimental treatment.

Statistical design, null hypothesis, statistical analysis

- Statistical design: Completely randomized design (CRD)
- Statistical analysis: One-way ANOVA
- Null hypothesis:
    - There are no differences in growth, production of carp, and gross profit margin among different polyculture systems.
    - There are no differences in biomass produced or biomass serially removed of SIS from ponds stocked at different densities.

Schedule

Experiment will begin 1 June 2014 and run 180 days; SIS production will continue to be monitored for 6 additional months; the report will be submitted no later than 30 August 2015.

IDENTIFYING LOCAL STRAINS OF *OREOCHROMIS NILOTICUS* THAT ARE ADAPTED TO FUTURE CLIMATE CONDITIONS

Climate Change Adaptation: Indigenous Species Development/Experiment/13IND01PU

Collaborating Institutions and Lead Investigators

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Kwame Nkrumah University of Science and Technology (Ghana)	Stephen Amisah
University for Development Studies and Technology (Ghana)	Gifty Anane-Taabeah
	Akwasi Ampofo-Yaboah

Objectives

1. Conduct a comprehensive review, a meta-analysis, and synthesis of the peer-reviewed literature on *Oreochromis niloticus*, with respect to various strains and their adaptive range for temperature, dissolved oxygen (DO), and salinity.
2. Conduct laboratory experiments to test the tolerance of the Volta strain and three wild populations of *O. niloticus* to increased temperature, decreased DO, and increased salinity.
3. Determine size distribution, sex ratios, and length-fecundity relationships and characterize ambient water-quality (temperature, DO, salinity) of *O. niloticus* in its native habitat along the latitudinal gradient from southern to northern Ghana in the Volta basin.
4. Genetically characterize wild populations of *O. niloticus* along the latitudinal gradient of the Volta River in Ghana.
5. Develop a predictive distribution model (i.e., zoogeography) for *O. niloticus* in West Africa and accurately delineate the extremes and boundaries of the species' native range.

Hypotheses for Experimental Studies

Hypothesis 1: The Volta/Akosombo strain of *O. niloticus* grows faster compared to the average wild population in Ghana under current climate conditions, but the Volta strain is less tolerant of high temperature, low dissolved oxygen, and high salinity than certain wild populations.

Hypothesis 2: Northern populations of *O. niloticus* in West Africa are more tolerant of high temperature, low dissolved oxygen, and high salinity than southern populations; and the northern populations have a higher optimum temperature for growth.

Significance

The world's climate is changing directionally and these changes will or are already having severe consequences for fisheries and aquaculture and food security, especially in tropical developing countries (Handisyde et al. 2005; Ficke et al. 2007; Stanturf et al. 2011; Leung and Bates 2013). Among impacts in aquatic systems expected to worsen over time include increased temperature and decreased DO, increased salinization of underground water and intrusion of salt water from sea level rise, and increased incidence of disease outbreaks in culture systems (Handisyde et al. 2005; Ficke et al. 2007; Williams and Rota 2010; Leung and Bates 2013). Recommended solutions emphasize adaptations and interventions that are based as much as possible on local practices and traditions, e.g., developing tolerant strains of existing aquaculture species and enhancing the resilience of communities, ecosystems, and traditional culture techniques (Williams and Rota 2010).

Nile tilapia (*O. niloticus*, or 'tilapia') is the most widely cultured species of fish in Africa and counted on for future food security and improvement of human nutrition, especially of the poor, in Africa. If this species succumbs to climate change, it will be a devastating blow to aquaculture development and the articulated vision for achieving food security through the Feed the Future program on the continent. Traditionally, strain selection and breeding has targeted a few traits, primarily fast growth (e.g., GIFT and its derivatives) and color, and other desirable traits are secondary. However, planning for climate change presents a different challenge; cultured strains have to both survive the climate and then grow rapidly. High temperature and low DO tolerance have not been primary traits for selection because the species is considered tolerant. Very little work has characterized salinity tolerance within or among populations of Nile tilapia, knowledge that would be valuable for designing a selective breeding program. There has been research on hybridization of *O. niloticus* with its salinity-tolerant confamilial species, e.g., *O. mossambicus* and *Sarotherodon galilaeus* (Kamal and Mair 2005; Yan and Wang 2010) and introduction of marine species DNA into gonads of *O. niloticus* (El-Zaeem et al. 2011), the goal being to develop more strains that can survive and grow better in high salinity (El-Sayed 2006). But introduction of genetically modified strains of *O. niloticus* into the native range would be opposed because of the threat of loss of pure wild populations. As an example, the use of GIFT strain in Africa for commercial purpose is still being debated after more than two decades of its development. On the other hand, the selection and development of better strains locally is encouraged. On this principle, the Volta strain of *O. niloticus* has been developed in Ghana and there are wide reports of promising performance (Dewedar 2013).

Optimal temperature for survival and growth of *O. niloticus* has been studied under a variety of conditions. Most studies found an optimum of 26-30^{o}C for growth, FCR and/or survival (Likongwe et al. 1996; Al-Asgah and Ali 1997; Baras et al. 2001; Azaza et al. 2008; El-Sayed and Kawanna 2008; Drummond et al. 2009; Xie et al. 2011). Perhaps, more intriguing is the variation observed in the optimum and the reduced growth and increased mortality past the optimum, well before the upper lethal temperature (Preceding references). Strain and acclimation conditions account for some observed variation, but what has not been studied well is whether optimum and lethal temperatures vary within the species. These studies often assume implicitly that the physiological adaptations of the species are the same for all populations and individuals, and that phenotypic plasticity explains observed variation in tolerances, although it is well-known in fishes that geographic cline in traits occur. For example, the mummichog *Fundulus heteroclitus* distributed along the east coast of the United States shows a latitudinal cline in temperature and oxygen use adaptation, with underlying genotypic variation in the allelic isozymes of lactate dehydrogenase (LDH-B) that affect ATP levels (Place 1983). Individual variation in salt tolerance in *O. niloticus* has also been studied at the molecular level, although not in the context of latitudinal clines (Rengmark et al. 2007).

Sub-Saharan Africa pond aquaculture is heavily dependent on natural ambient DO as aeration is rare to non-existent and mostly unnecessary at moderate stocking densities. Tolerance of *O. niloticus* to low DO should be understood in the context of minimum DO required for acceptable survival, growth, and reproduction. Under recirculating conditions, *O. aureus* had better FCR with intermediate (3.75±0.12 ppm), compared to low and high DOs (Papoutsoglou and Tziha 1996). DO levels do not only influence feed intake in *O. niloticus*, but it also affects growth, size at maturity, gonadosomatic index (GSI), egg size, and absolute fecundity (Kolding et al. 2008; Tran-Duy et al. 2008). There are well known dependencies among temperature and solubility of salt and oxygen, and plastic response of fish to one physicochemical variable also depends on the level of other variables, in addition to interaction of genetics with environmental factors (Charo-Karisa et al. 2006; Schofield et al. 2011). A quick search of Web of Science and Aquatic Sciences and Fisheries Abstracts databases for the period 1970-2012 revealed more than 1,100 peer-reviewed publications on *O. niloticus* and and confamiliar species that focus on some aspect of growth. However, on close examination, West Africa native strains of *O. niloticus* are grossly under-represented in these studies. Most studies are from Egypt or otherwise from outside of the continent. Identification of better-adapted populations of *O. niloticus*, and degree of adaptation to temperature, DO, and salinity will require synthesis of existing knowledge on the species, a combination of field and laboratory studies, including basic genetic descriptions, and linkage of distribution with biophysical data.

Species exhibit their most extreme adaptations at the extremes ends of their range and in response to environmental gradients (e.g., Place 1983). In West Africa natural climate varies from humid forest to dry savanna and desert as you move from the coast (low latitude) to interior (high latitude). The Volta basin, which spans the entire length of Ghana into Burkina Faso, aligns with this gradient. Reported occurrences (Paugy et al. 2003) indicate that *O. niloticus* range crosses much of the climate gradient. Populations in hot, drought-prone areas are predictably better adapted to high temperature, low DO, and high salinity. The salinity prediction is less intuitive but not when you consider that aquatic systems subject to high evaporation tend to have higher salinities, as drying concentrates dissolved solids. Thus, the predicted climate change scenarios in the southern parts of Ghana where most aquaculture is concentrated is very similar to current conditions in the north, near the upper limit of known *O. niloticus* West African range. A more accurate zoogeographic model for *O. niloticus* would be useful as a tool to identify the best adapted populations and also delineate the species' range from the numerous cichlid species (more than 40 in West Africa, Paugy et al. 2003) that are undoubtedly confused with *O. niloticus*, especially by small-scale farmers who still rely significantly on wild brood and seed to stock their ponds. Identifying these populations and their adaptations will guide future breeding programs that will have to consider climate, and take advantage of individual variation within among populations to select for desired traits in addition to fast growth.

<u>Quantified Anticipated Benefits</u>

- At least one peer-reviewed manuscript synthesizing current knowledge on *O. niloticus* with respect to physiological adaptive range of the species and how this information can be used to inform climate change adaptation strategies.
- A minimum of three distinct wild populations of *O. niloticus* and the Akosombo strain characterized in terms of tolerance to temperature, dissolved oxygen, and salinity.
- Length-fecundity relationships developed for of three wild populations of *O. niloticus*.
- A DNA library created for at least three wild populations of *O. niloticus* in Ghana.
- An accurate fine-grained West African distribution map of *O. niloticus* created to help identify extreme and likely better-adapted populations of *O. niloticus* for future climate.

<u>Study Design and Activity Plan</u>

Location

Study will be conducted in Ghana in the Volta basin. Ghana is ideal for this study because O niloticus is native throughout most of the nation's geographic boundaries and spans the three biogeographic regions (forest, semi-deciduous, and savanna) over 5-6 degrees of latitude.

Methods

The following five components of the work plan follow the five objectives previously listed:

A. A comprehensive literature review and a meta-analysis and synthesis of the peer-reviewed and other credible literature on *O. niloticus* performance under varying water physico-chemistry will focus on which of these factors and corresponding adaptations will have the most significant effect on survival and growth under future climate. Data will be extracted from published studies and standard statistical meta-analysis techniques will be employed. The overarching goal will be to synthesize what we already know that is useful in guiding climate adaptation strategies.

B. Experiments will be conducted to test the tolerance of the Volta strain and three wild populations (tentatively 'strains') of *O. niloticus* to increased temperature, decreased DO, and increased salinity. Fingerlings (~5g) will be obtained from a trusted commercial or government hatchery (Volta strain) and three wild populations of *O. niloticus* will be collected from the south humid forest, semi-deciduous, and savanna (near the northern border of Ghana) bioregions. Reconnaissance surveys of potential field sites will be conducted to verify the existence of thriving populations of *O niloticus*. Wild fingerlings will come from sites established for field studies.

Fish will be reared in aquarium tanks with recirculated water at appropriate stocking densities. Each of the three factors will be varied at two levels: The low DO will be achieved by absence of aeration while the high (control) level will be achieved by aeration of the source water (e.g., Tran-Duy et al. 2008). Temperature will be regulated by heater/chillers. The control temperature will be maintained at 28^{o}C and the high at 32^{o}C. The control level of salinity will be approximately 0ppt (i.e., no salt added) and the high salinity will be created by adding appropriate quantity of crude natural salt or brine to raise salinity to 15ppt. Dry runs will be conducted months prior to the experiment to perfect the temperature, DO, salinity settings within the narrow ranges desired. In addition, during the actual experiment water quality will be monitored at the inlet at least three times a day and the levels of these three variables will be adjusted immediately if needed. Prior to experiments all fish will be acclimated at the control conditions. Detailed experimental design will depend on the number of fingerlings obtainable from the field, and the degree to which reproduction timing is synchronized among the different populations in the study region. The option to produce fingerlings from spawns and standardize early life history will be explored. A factorial design is desired but in the possible event of wild populations reproducing at significantly different times a split-plot design will be considered. Each treatment combination will have 3 replicates to result in 4(populations) X 3(factors) X 2(levels) by 3(replicates) = 72 experimental units. Size-matched fish could be individually marked and reared communally to remove experimental unit as a variance contributing factor. Experiments will run for approximately 60-70 days, i.e., before fish reach maturity and growth will be measured weekly on a subsample of fish. Survival will be determined by subtracting mortalities. Fish will be fed high-quality commercial floating feed to apparent satiation and amount of feed taken by each experimental unit will be documented to determine FCR.

C. Size distribution, sex ratios, and length-fecundity relationships of *O. niloticus* and ambient water-quality (temperature, DO, salinity) in its native habitat along the latitudinal gradient will be studied through standard field sampling using seine and other gear as locally applicable and based on river size considerations. Water quality meters will be used to measure physico-chemical variables *in situ*. Field studies will cover a period of at least 6 months with sampling once a month to capture reproductive season and to determine the best time to collect wild fingerlings for experimental studies. Specimen for laboratory analysis will be preserved first in 10% formalin and then in 70% ethanol and prepared for analysis following standard ichthyologic techniques.

D. To genetically characterize populations of *O. niloticus* used for experimental studies and wild populations along the latitudinal gradient of the tributaries of the Volta Lake, PCR-based techniques for DNA fingerprinting using nuclear microsatellite (lee and Kocher 1996) and mitochondrial DNA (Rognon and Guyomard 1997) markers will be employed. Fin clips will be taken in the field and preserved in alcohol (i.e., no formalin fixation) to maintain the integrity of DNA in the samples. Samples will be shipped to Virginia Tech University, where all these DNA marker techniques are in regular use .

E. To develop a predictive distribution model for *O. niloticus* in West Africa and accurately delineate the extremes and boundaries of the species' native range, occurrence records for *O. niloticu*s will be obtained from published sources (e.g., Paugy et al. 2003; Fishbase www.fishbase.org). Environmental data such as temperature, elevation, and annual rainfall averages will be obtained from online GIS databases (e.g., www.madmappers.com). Some environmental data, especially the more accurate and climate-relevant may be available at a cost. Standard 'niche' modeling (e.g., Zambrano et al. 2006) and other improved techniques will be employed. Such a map can also be used to examine how the natural distribution of the species will change under future climate scenarios.

Schedule

Activity/Month	J-S 201 3	O-D 2013	J-M 201 4	A-J 201 4	J-S 201 4	O-D 2014	J-M 201 5	A-J 201 5	J-S 201 5
Literature review and meta-analysis	x	x	x	x					
Field Reconnaissance	x								
Field studies		x	x	x	x	x			
Laboratory analysis of field data			x	x	x	x	x	x	
Laboratory dry runs/Experiments		x	x	x	x	x	x		
Genetic analysis						x	x		
Acquisition of distribution data	x	x	x						
Distribution modeling			x	x	x	x			
Data analysis and reporting						x	x	x	x

SUSTAINABLE SNAKEHEAD AQUACULTURE DEVELOPMENT IN THE LOWER MEKONG RIVER BASIN OF CAMBODIA

Climate Change Adaptation: Indigenous Species Development/Experiement/13IND02UC

Collaborating Institutions and Lead Investigators

University of Connecticut-Avery Point (USA)	Dr. Robert Pomeroy
Inland Fisheries Research and Development Institute (IFReDI)	Dr. So Nam Mr. Nen Phanna
Can Tho University (Vietnam)	Dr. Tran Thi Thanh Hien

Objectives

1. The specific objectives of this investigation are as follows.
2. To optimize the domestication breeding and weaning of the wild striped snakehead *Channa striata* to address the snakehead banning issue in Cambodia in order to lift the ban on snakehead aquaculture in Cambodia;
3. To evaluate the survival rate and growth performance of the striped snakehead *Channa striata* in different forms of culture practices by using practical formulated diets as a result of climate change;
4. Assess economic efficiency of experimental grow-out of the striped snakehead *Channa striata*; and to provide recommendations for policy and best practices for the development of snakehead farming in Cambodia.

Significance

In Cambodia wild snakeheads are generally cultured in smaller cages and ponds. Feed represent more than 70% of the total operational cost and the main type of feed for wild giant snakehead culture is small-sized or low valued fish, representing 60 to 100% of the total feed used depending on feeding strategies adopted by different farmers (So et al., 2005). During the dry season (October to May), the most important source of feed is freshwater small-sized or low value fish, while more marine small-sized or low value fish species are used during the rainy season (June to September) (So et al., 2005). Importantly, the snakehead production contributes more than 70% of total aquaculture production in Cambodia due to its popular fish food and high market and trade demand in Cambodia as well as in Viet Nam Snakeheads are very popular fish food, which can be found in most Cambodian and Vietnamese dishes at all wealth class levels (i.e. from poor, medium to rich people).

The government of Cambodia put a ban on snakehead farming in September 2004 by the Announcement No. 4004 kor.sor.ko.sor.chor.nor and the reasons for this was the potential negative impacts on wild fish populations from wasteful snakehead seed collection and on other fish species diversity, particularly the small-sized or low value fish used feed for snakehead aquaculture, and also potential negative effects on poor consumer groups from decreased availability of small-sized/low valued fish due to dependency of snakehead aquaculture on small-sized/low valued fish (So et al, 2007). In order to remove this ban, the same Announcement mentioned that successful technologies of domestication breeding, weaning and rearing/growing-out of snakeheads using formulated diets should be developed and applicable in on-station and on-farm levels in Cambodia.

In addition, Cambodia is highly vulnerable to the effects of climate change on aquaculture and fisheries, which supply livelihoods for millions and up to more than 75% of all animal protein in the diet (Allison et al., 2009; Halls et al., 2012). However, aquaculture and fisheries can help solve other adaptation problems. As rising sea levels and increased flooding may render some existing farmland unsuitable for cropping, fish cultivation can provide alternative livelihoods and offset these losses. Further, water and nutrients from fish ponds can improve farm productivity and sustain it under drought (WorldFish Center, 2007). Conserving wild fisheries and enhancing aquaculture should be considered twin strategies of adaptation to climate change.

During the first phase of AquaFish CRSP (2007-2009), the Investigation # 2 revealed that nearly 200 freshwater small-sized fish species were detected in the Mekong River Basin of Cambodia and Vietnam, and these freshwater small-sized fish species, including juvenile of commercially important fish species, contribute more than 70% to total freshwater capture fisheries production. After the ban on snakehead culture in Cambodia, snakeheads have illegally been imported from the neighboring countries, particularly from Vietnam, to supply high local market demands in Cambodia. Furthermore, the study showed that freshwater small-sized fish have illegally been exported to Vietnam for feeding the significantly and commercially developed snakehead aquaculture in Vietnam. The first phase study also indicated that the incentives for choosing snakehead before other fish species by tens of thousands of fish farmers are strong as it generates more than 10 times higher profits than other fish species. Therefore, the ban does not only result in positive impacts on poor consumer groups from increased availability of freshwater small-sized fish in Cambodia, but also providing negative effects on food and nutrition security and livelihood of tens of thousands of snakehead farmers who depend on this livelihood for improving household food and nutrition security and generating household income. In other words, these snakehead fish farmers have lost their important livelihoods and household income. Moreover, the ban also does not provide positive impacts on snakehead wild stocks as fishing pressure on wild snakehead using illegal and destructive fishing gears particularly electro-shockers has been increased for the recent years in order to supply local and external markets.

During the second phase of AquaFish CRSP (2009-2011), the wild striped snakehead *Channa striata* broodstocks were successfully developed, mature and semi-artificially induced spawning using the hormone HCG on-station in Cambodia (So et al, 2011). The striped snakehead *Channa straita* aging 30 days old after hatch could gradually and successful accept AquaFish CRSP Snakehead Formulated Feed developed by AquaFish CRSP project (Hien and Bengtson, 2009; 2011) in replacement of small-sized fish in the rate of 10% every three days for a period of 30 days of feeding (So et al., 2011).

This study will focus on optimization of domestication breeding and weaning of the wild striped snakehead *Channa striata* and assessment of survival rate and growth performance of the striped snakehead *Channa striata* in different forms of culture practices (i.e. earthen ponds, hapa-nets and cement tanks) as result of climate change (i.e. temperature).

<u>Quantified Anticipated Benefits</u>

This research will provide information on domestication breeding, weaning and growing out of snakehead fish, especially development of Cambodia's snakehead aquaculture technologies, in order to lift the ban on snakehead culture in Cambodia. The followings are quantifiable anticipated benefits:

1. At least 20,000 farmers in Cambodia will benefit from this Investigation by restarting their snakehead culture leading to increased household income and improved snakehead fish market and trade
2. 250 scientists, researchers, government fisheries officers/managers and policy makers, extension workers, NGO staff, and private sector working on the issues of snakehead aquaculture in Cambodia as well as in other Mekong riparian countries will be better informed and consulted of research methods and findings, and have better recommended policies and strategies for sustainable snakehead aquaculture.
3. Two (under)graduate students will be supported and trained by this investigation through their B.Sc./M.Sc. thesis research. One student will come from Royal University of Agriculture and another from Preak Leap National School of Agriculture, Phnom Penh, Cambodia.
4. At least 1,000,000 indirect beneficiaries in Cambodian and other Mekong riparian countries who consume snakehead fish in their protein diets leading to improved their household food and nutrition security

5. Benefits to the US include improved knowledge and technologies on domestication of freshwater fish species for aquaculture and this aquaculture is considered as a climate change adaptation measure.

Research Designs or Activity Plan

Location of work

All domestication breeding, weaning and growing out trials in different forms of culture practices to evaluate survival rate and growth performance as a result of climate change, with the focus on temperature change/variation will be conducted at Freshwater Aquaculture Research and Development Center (FARDeC), Prey Veng province, Cambodia under the direct supervision of the Inland Fisheries Research and Development Institute (IFReDI), which has many broodstock, breeding and weaning earthen ponds, hapa-nets and cement tanks, a small fish feed mill for fish pellet production and laboratories. Training of IFReDI researchers and staff on snakehead domestication breeding, feeding, weaning, growing out and wet and dry diet formulation will be done at Can Tho University (CTU), Vietnam based on information obtained from the first and second phases of AquaFish CRSP Investigations by Prof. Dr. David Bengtson, University of Rhode Island and Dr. Tran Thi Thanh Hien, Can Tho University.

Methods

This study will comprise six interrelated parts:

- Collection of wild snakehead fish:
  In addition to available breeders, adult/mature wild snakehead (Channa striata) from different natural water bodies will be collected and stocked at IFReDI/FARDeC hatchery, Cambodia.
- Conduct of training and technology transfer:
  On-the-job/site training of IFReDI/FARDeC researchers and staff on snakehead breeding, weaning, feeding strategies, growing out, and feed formulation techniques (feed formulation based on the optimal diet composition: protein, lipid, mineral, fiber and energy obtained from the first and second phases of AquaFish CRSP, and on supplemented information from Samantary and Mohanty, 1997; Arockiaraj et al, 1999) will be conducted at Can Tho University, Vietnam.
- Optimization of induce spawning techniques using the hormone HCG:
  After FARDeC/IFReDI researchers returning from Vietnam and knowing what they are doing, they will start inducing the collected wild snakehead to spawn using different doses of the hormone HCG
  Optimization of weaning techniques using live feed (i.e. moina) , freshwater small-sized fish and formulated feed to produce snakehead fingering (2 month-old fish) that can eat pellets during grow-out.
- Development of grow-out techniques using AquaFish CRSP Formulated Feed to produce market-sized fish:
  The null hypothesis for this experiment is: There is no significant difference in fish survival, fish growth, or diet cost-effectiveness among the treatments listed.
  Three unstructured experiments will be individually designed for earthen ponds, hapa-nets and cement tanks, and each experimental culture unit will be composed of the same five treatments with three replicates per treatment to see if CRSP Formulated Feed (FF) diet can replace most or all of traditional Small-Sized Fish (FSF) diet for snakehead Channa striata grow-out in Cambodia. We will also compare the five treatments to find out which the best and most cost-effective feeding approach is as following:
  - Treatment1: 100% freshwater small-sized fish (FSF) as control x 3 replicates
  - Treatment 2: 70% FSF + 30% formulated feed (FF) x 3 replicates
  - Treatment 3: 50% FSF + 50% FF x 3 replicates
  - Treatment 4: 30% FSF + 70% FF x 3 replicates
  - Treatment 5: 100% FF x 3 replicates

Water temperature, pH, ammonia, nitrite and dissolved oxygen will be recorded weekly. Fish will be sampled monthly to estimate mean weight and dead fish will also be recorded . At harvest, all fish will be harvested, counted, weighed and the mean fish weight and survival from each treatment of experimental units determined.

Cost and benefit (budget) analysis will be conducted to determine economic returns and efficiencies of *Channa striata* in the different treatments of each culture unit as the following formulas:
-Total Revenue = Quantity * Price/unit
-Total Cost =Variable Cost + Fixed Cost
-Net return = Total Revenue – Total Cost
-Economic Efficiency = Total Revenue/Total Cost

The analysis will be based on farm-gate prices in Cambodia for harvested *Channa striata* and current local market prices for all other items (e.g. cost of the traditional freshwater small-sized fish and cost of the formulated feed) will be expressed in US dollars (US$).

Data including yield, growth, survival and economic return and efficiency in the different treatments of the culture unit, will be statistically analyzed and compared using analysis of variance with SPSS (version 11.0) to test for significant differences and Duncan's multiple range test will be used to discriminate which means are significantly different from each other. Differences are considered significant at an alpha of 0.05.

Schedule

The duration of implementation of this proposed investigation will be 24 months, starting from 1 October 2013 till 30 September 2015.

This investigation is planned to be implemented as below:

Activity	Beginning	Ending
Experimental designs	August-2013	August-2013
Hand-on training at Can Tho University	August-2013	Agust-2013
Implementation of the experiments	Sept-2013	December-2014
Analysis of results and report preparation	January-2014	June-2015
National workshop on "Consultation and dissemination of research findings	July-2015	July-2015
Finalization of final technical report	August-2015	Sept-2015

Deliverables

The deliverables of this investigation will include (1) final technical report, including policy recommendations, and (2) factsheet.

DEVELOPMENT OF LOW-COST CAPTIVE BREEDING AND HATCHING TECHNOLOGIES AND MANAGEMENT PRACTICES FOR TWO AFRICAN LUNGFISH SPECIES (*PROTOPTERUS AETHIOPICUS* AND *P. AMPHIBIUS*) TO IMPROVE LIVELIHOODS, NUTRITION, AND INCOME FOR VULNERABLE COMMUNITIES IN UGANDA

Climate Change Adaptation: Indigenous Species Development/Experiment/13IND03AU

Collaborating Institutions and Lead Investigators

Auburn University (USA)	Joseph Molnar
	Claude Boyd
National Fisheries Resources Research Institute (Uganda)	John Walakira

Objectives

1. Determine the genetic diversity of the endemic African lungfish (*Protopterus aethiopicus*) fingerlings sourced from four Agro-ecological Zones (East, North, South western and Central) of Uganda.
2. Domesticate the African lungfish using simple, adoptable and productive captive breeding techniques that integrates indigenous knowledge.
3. Assess the reproductive performance of the African lungfish in captivity.
4. Evaluate the culture performance of two African lungfish species raised to market size in small-scale fish ponds.

Significance

The marbled lungfish (*P. aethiopicus*) and the gilled African lungfish (*P. amphibius*) is an endangered fish species in Uganda. Their natural stocks are rapidly declining mainly due to overexploitation, environmental degradation, and the large-scale conversion of wetlands to agricultural land. Uganda has nine million people facing an acute food shortage, while 38 % of its children are chronically malnourished. Aquaculture is one part of the response to these challenges.

Climate change continues to influence regional rainfall patterns and temperature regimes. Many small and medium-scale producers struggle with poor water quality (e.g. low dissolved oxygen) and seasonal water deficits that constrain the management of aquaculture systems in sub-Saharan Africa. The African lungfish (an air breather) may offer some distinct advantages for income generation for small-scale fish farmers as a high value product grown under controlled conditions.

Lungfish is valued and demanded in Uganda. It has a distinct flavor, and is associated with various positive and negative beliefs among different ethnic groups in different locales (Kees 2002). Nonetheless, consumer acceptance of the fish seems high and widespread, but it lacks appropriate culture technologies that would enhance its ability to increasing income generation for small-scale fish farmers. A small number of farmers currently obtain seed from the wild, grow lungfish in earthen ponds, and usually receive disappointing results. We do not yet know how to reproduce the species, to best feed the fish, or how to manage its growth and harvest.

The absence of breeding technologies for this fish limits the possibilities for lungfish culture until seed stock can be made more widely available. This study seeks to develop sustainable breeding and appropriate culture techniques for two African Lungfish species using commercially available fish feeds. If feasible, culturing lungfish has the potential to improve nutrition, food security, and increase income for human populations. It also will also reduce pressure on wild fish stocks in Uganda.

Quantified Anticipated Benefits

The following expected benefits are to be achieved by the project:

1. Basic guidance on management of lungfish expressed in a farmer-oriented leaflet.

2. Basic nutrition profile of lungfish grow out expressed in a technical report for extension
3. Basic fingerling supply and grow out information expressed in a journal article.
4. Inform the merit of continuing research into developing low-cost, artificial breeding technologies for these species.

Research Design

Location of work

Aquaculture Research and Development Center-Kajjansi.

Methods

Study 1. Determining the genetic diversity of the endemic African lungfish.

Experiment 1.1: Genetic diversity of African lungfish in Uganda: relatedness based on SNPs and microsatellite markers.

African lungfish fingerlings will be obtained from four agro-ecological zones (east, north, south western and central) of Uganda, and their reproductive biology performance in captivity assessed. Recent approaches to measuring genetic diversity within wild and farmed fish populations have underscored the use of Single Nucleotide Polymorphisms (SNP) and microsatellite (MS) markers. SNPs are considered to be more powerful markers because of their flexibility to automation and their high resolution. SNPs can more readily reveal hidden polymorphisms compared to other markers (Zhang, et al., 2012). SNPs also can facilitate for sex determination in fish (Chen et al., 2013; Bradley et al., 2011; Kikuchi and Hamaguchi, 2013). Nevertheless, both methods can help assess genetic variation among African lungfish.

Profiling genetic variation is a fundamental step in toward the development of captive breeding programs (Liu and Cordes 2004). Hence, we can develop strategies to domesticate African lungfish in Uganda and the sub-Saharan African region using advanced molecular approaches. The protocol used here will build on procedures described by Ball et al. (2010), DeFaveri et al. (2013), Garner, et al. (2006) and Muwanika, et al. (2012).

a) Sample collection, morphometrics and sex identification.

African Lungfish measuring 60-100 cm, total length, will be collected from four sources; Lakes George-Edward, Kyoga-Nawampasa, Wamala and Bisina-Opeta system. It is assumed that fish at this size range will be mature. Approximately 40-60 fish per site will be collected using locally available harvesting gears. Site sources will be mapped using GIS technologies to specify location. We will seek the cooperation of local fishing communities and district officials who will guide the identification of lungfish water bodies and aggregation points. Fish will be anesthetized with tricaine methanesulfonate (ms-222) buffered with 0.2 ml $NaHCO_3$, pH = 7. Morphometric parameters will be measured following the "Truss Network System" (Strauss and Bookstein, 1982; Dwivedi and Dubey, 2012) focusing on the geometric morphology of the African lungfish. Each fish will have *n* homologous anatomical landmarks. These selected *n* inter-landmark distances (modification of Cavalcanti et al., 1999) will be characterized using digital images to determine the differences among wild populations of different agro-ecological zones (AEZs). Data will be subjected to statistical analysis as described by Mir et al. (2013) to evaluate significance differences among populations investigated.

The fish samples will be dissected to identify individual sex, which will be correlated to phenotypic observations based on existing scientific and indigenous knowledge. Molecular markers will be identified to ascertain and explain sex differentiation and determination of African lungfish since this information is apparently unknown. Environmental parameters will be measured taken to understand their effects on fish sex determination and differentiation following the Baroiller et al. (2009) method. This information may facilitate sexing the African lungfish, a basic procedure in captive breeding programs.

b) DNA extraction, SNPs and Microsatellite genotyping.
Genomic DNA will be extracted from fin clips and/ or skeletal muscle tissue samples using standard procedures and a DNA isolation kit available on market. SNP and MS genotyping will follow methods described by Ball et al. (2010), with modifications, to show relatedness or diversity among African lungfish from different locations. Phylogenetic analysis will be applied to clarify the genetic variability of this fish in Ugandan waters. Information generated will enhance strategies to improve future brood-stocks of African lungfish.

Experiment 1.2: Reproductive biology of African lungfish in captivity.
The maturity of African lungfish under captivity must be determined as part of the reproductive biology of African lungfish. Wild collected fingerlings (± 20g) will be tagged and stocked in enclosed cages (2x 2x4 m2) staged in three replicates, in earthen ponds. The environment is designed to model natural conditions (e.g. adding aquatic weeds) representing populations (males and females) pooled from each AEZ.

Fish will be fed commercially available fish feed supplemented with natural food (e.g. molluscs) to ensure quick acclimatization. Monthly samples (N=10) will be taken and gonadal development (e.g. gonadal-somatic index) and survival rates will be evaluated and characterized to understand the maturity of this fish under captivity. Water quality parameters will be monitored weekly to determine effect of environment on maturity. Best performing fish will be selected for future artificial breeding trials of the African lungfish. This study will be done in collaboration with the Department of Fisheries and Allied Aquaculture (FAA), Auburn University (USA) and College of Natural Science (CNS), Makerere University (Uganda).

Study 2. Domesticating the African lungfish using simple captive breeding techniques that integrate indigenous knowledge.
To ensure an environmentally sustainable supply of African lungfish seed to fish farmers, artificial breeding and hatching technologies will have to be developed. Simple and low-cost breeding technologies will be needed in rural communities that are dependent on this fish. Mature brood-stock from *study 1* and selected wild populations will be subjected to simple artificial reproduction techniques to determine fecundity, egg production, larval quality, hatchability and larval survival.

Experiment 2.1: Artificial breeding of African lungfish in captivity
Modifying protocols used by Vijaykumar et al. (1998), mature broods stocked in concrete tanks at NaFIRRI will be treated with two selected hormones (natural and synthetic) to induce spawning. The analysis will examine fecundity, hatchability and survival of post-hatchlings. Water quality parameters will be monitored weekly to understand environmental factors affecting artificial breeding. Best approaches will be selected based on statistical analysis of factors that produce better quantity, viability, and quality of lungfish spawn.

Experimental 2.2: Natural breeding of African lungfish in captivity
Selected mature brood-fish (males and females) from study 1 and those fresh from wild waters will be stocked in concrete tanks or hapas suspended in earthen ponds, then covered with macrophytes (e.g. water hyacinth (Eichornia crassipes)) that are usually present in natural breeding habitats. Water levels will be manipulated to stimulate natural ovulation, spawning, and fertilization. Fecundity, hatchability and survival of post-hatchlings will be evaluated. Water quality parameters will be monitored, weekly, to understand environmental factors affecting artificial breeding. Best approaches will be selected based on statistical analysis of factors that produce better quantity, viability, and quality of lungfish spawn.

Study 3. Evaluating the grow-out performance of African lungfish produced in captivity and reared in ponds under different management practices.
To assess the relevance and contribution of African lungfish aquaculture to communities dependent on this fish, on-farm trials will be conducted. Lungfish fingerlings will be raised in concrete tanks or cages in ponds at selected fish farms: preferably, two fish farmers per AEZ.

Three stocking densities (50, 100 and 150 fish per m^3) will be tested for survival, growth, and yield under different management practices. Monthly samples will be obtained to measure growth performance, feed effeciency, and survival rates.

Results will be analyzed using statistical tests to identify significant differences in growth rates between treatments. Statistical analysis will also be conducted to determine survival and feed efficiency between treatments and management regimes. Results will inform best management practices and ideal rearing conditions (stocking densities and feeding regimes) for fingerlings. Factors relating to the biology of this species that could negatively affect its success as an aquaculture candidate (cannibalism, piscivory, territorialism, burrowing) will be assessed during the grow-out trials. These will be considered along with grow-out performance results and socio-economic factors to determine the suitability of this species for culture in Uganda.

A workshop will be held at the 2015 meeting of the WAFICOS fish farmers cooperative in Uganda to disseminate the results of the grow-out experiment to members. An informal survey of participants will be conducted at the meeting to identify current interest for and perceptions of culturing this species as a high value alternative to tilapia and catfish. Potential collaborators will be identified for future application of research.

Schedule

Task	**8/2013**	**11/2013**	**2/2014**	**5/2014**	**8/2014**	**11/2014**	**2/2015**	**5/2015**
Collect Fingerlings From 4 Zones	**X**	**X**	**X**	**X**				
Develop Captive Breeding		**X**	**X**	**X**	**X**			
Assess Reproductive Performance				**X**	**X**	**X**	**X**	
Assess Captive Growth						**x**	**x**	**x**

Deliverables

Item	**Mechanism (e.g. podcast reports factsheets etc.).**
Captive breeding results	Basic Nutrition Profile Of Lungfish Grow Out Expressed In A Technical Report For Extension
Captive reproductive results	Journal Article
Captive growth results	Basic Guidance On Management Of Lungfish Expressed In A Farmer-Oriented Leaflet
Workshop/Survey	WAFICOS Meeting And Presentations To Fish Farmers Cooperative

TOPIC AREA

QUALITY SEEDSTOCK DEVELOPMENT

❖

SPAT COLLECTION AND NURSERY METHODS FOR SHELLFISH CULTURE BY WOMEN

Quality Seedstock Development/Experiment/13QSD01PU

Collaborating Institutions and Lead Investigators

University of Hawaii at Hilo (USA)	Maria Haws
University of Dar es Salaam (Tanzania)	Narriman Jiddawi
Western Indian Ocean Marine Sciences Association (WIOMSA) (Tanzania)	Julius Francis

Objectives

This work builds on eight years of efforts to develop a small-scale bivalve shellfish culture industry in Zanzibar to increase food security and family income with women being the primary participants. Specifically, this work will address one of the primary obstacles to further development of the small shellfish farms-how to obtain stock in a sustainable manner for the farms. Spat collection is one of the most sustainable and cost-effective methods to obtain stock for shellfish farms, hence methods will be tested to determine the best materials and timing for spat collectors, and test nursery methods to rear the collected spat. Women will also be provided training in other shellfish farming methods beyond the nursery stage.

Introduction

Zanzibar has recently been the site for innovative work that combines development of aquaculture with integrated coastal management and fisheries management to implement alternative livelihoods. Zanzibar consists of two main islands and a number of small islands in the East Coast of Africa. The total area of both islands is 2,643 km2 (Unguja 1658 km2 and Pemba 985 km2). The population is estimated to be around 1,300,000 people, growing at 3.1 % annually. Fishing is the most common coastal activity and is 95% artisanal, mostly operating in shallow water using traditional vessels and gear. However, the artisanal fisheries are now considered to be overfished (Jiddawi, 2012) which has stressed local villages and the economy. Alternative to fishing are a high priority of the national and local governments.

The residents of Zanzibar suffer from multiple nutrition and health issues related to poverty and marginalization. Of children under five years of age, 35% are stunted, 25% are underweight and 6% are wasted, resulting in approximately 130 child deaths per day (ZPRP 2002). This is one of the highest rates amongst areas in Tanzania. Nutritional problems include protein/energy, iodine and Vitamin A. Bivalve shellfish are good sources of protein, vitamins (C, B1, B2, B3, D) and nutrients such as calcium, iron, copper, iodine, magnesium, zinc, manganese and phosphorus. Hence farming of bivalve shellfish represents a direct means of improving nutrition through local consumption, as well as an indirect means since women also sell bivalve products to support basic family needs.

The proposed work builds on eight years of efforts to develop a small-scale bivalve shellfish industry led by women stakeholders in East Africa. These efforts have had successful results in that over seven coastal villages now engage in some form of bivalve shellfish farming.

Coastal women have traditionally utilized reef-gleaning of bivalves, other invertebrates and small fish as one of their livelihoods, and as the principal source of high protein food. This traditional livelihood is threatened by: 1) increasing populations; 2) migration of inland populations to the coast; 3) development for tourism which excludes villagers; and 4) over-fishing. Climate change may also affect women's livelihoods. For example, seaweed farming has been a mainstay for coastal women for over twenty years but recent disease outbreaks have lowered production (Msuya et al. 2007) and may be linked to increased sea surface temperatures. Since 1998, a team of partners including the Institute for Marine Sciences (IMS), Tanzania Coastal Management Partnership (TCMP) and the Western Indian Ocean Marine Sciences Association (WIOMSA) have led efforts to improve marine resource management, improve coastal management, build awareness for ICM and conservation, provide alternative livelihoods and conduct relevant research. These partners were supported by the national and local governments, and a wide array of universities and international donors.

Most recently, the partners were supported by the Coastal Resources Center of the University of Rhode Island (CRC/URI) and the Pacific Aquaculture and Coastal Resources Center at the University of Rhode Island (PACRC/UHH) to focus on protecting and sustainably utilizing the coastal shellfish resource. This work was supported by USAID through the Sustainable Coastal Communities and Ecosystems (SUCCESS) Program, along with other donors such as the MacKnight Foundation and the European Union ReCoMap (Regional Coastal Management Programme). Successful efforts previously supported by USAID include:

- Establishment and community-based monitoring of Marine Protected Areas (MPAs) to protect cockle (Anadara spp.) populations, a mainstay of the coastal diet;
- Development of bivalve shellfish farming led by women farmers;
- Piloting of pearl production and production of half-pearl jewelry by women;
- Initial testing of spat collection methods for a variety of bivalve species; and
- Development of a cottage industry utilizing discarded mollusk shells to make jewelry.

This work has been modeled on the successful efforts to develop seaweed farming by women along the East African coast which is now a major coastal industry. Many of the women shellfish farmers have also engaged in seaweed farming, hence they have a basic knowledge of aquaculture. Shellfish farming has equal potential if technical support is provided so that existing methods can be refined.

Despite the success of the initiatives listed above, these are still new economic activities which continue to need technical support and further applied research to make more profitable, scale up and become more sustainable. These efforts support food security both directly and indirectly. Bivalve shellfish are an important source of protein and micronutrients for women and children. They are commonly the only source of protein that this group can access on a daily basis. Shellfish are also one of the main sources of income for coastal women, and the new cottage industries of producing shell jewelry and half pearls has significantly increased women's incomes. It has been documented that Zanzibar women use income from these activities for children's school fees, food, and clothing and to improve their housing (Crawford et al. 2010; Haws et al. 2010). Hence stabilizing and scaling up bivalve culture offers a feasible approach to improving food security and income for coastal women and children.

Significance

Women have been leaders in coastal aquaculture in East Africa being the first to culture seaweed, which has become the major type of coastal aquaculture. The shellfish farming development efforts started eight years ago were modeled on the seaweed farming efforts, both of which were supported by the research and extension efforts of IMS and WIOMSA. Shellfish farming was a natural activity for women to adopt since they were already familiar with many bivalve species due to their reef-gleaning activities. Initially women began shellfish farming in a low intensity fashion by placing smaller specimens of the bivalves they collected from reef areas in small, fenced-in enclosures in the intertidal area to allow these to grow to eating size. The purpose of the "fences", made of short stakes, was not primarily to contain the bivalves, but rather to designate the area claimed by the woman farmer and to prevent other intertidal users from treading on the enclosed bivalves. Subsequently they found that the stakes provided good substrates for spat collection, as high numbers of spat naturally attached to the stakes. These specimens were added to the "farmed" bivalves in the enclosed area. Women typically gather, consume and sell nearly every bivalve species (*Ostrea spp., Crassostrea spp., Isognomen spp., Donax spp., Anadara spp.*) found on the intertidal flats (~15 common species), including two species of pearl oysters, *Pinctada margaritifera* and *Pteria penguin* (Jiddawi 2008). The latter two species have been utilized for half-pearl production on a limited basis on Zanzibar and Pemba Islands. Hence, unlike single species industries which target specific species for spat collection and hence encounter issues with high rates of collection of undesirable species, shellfish farmers in Zanzibar have the luxury of being able to utilize nearly all bivalve species collected on any spat collector. Of course, developing methods which would optimize collection of the higher value species such as oysters and pearl oysters would be most advantageous.

Collection directly from the reef and intertidal areas and grow-out of small specimens is not necessarily the most sustainable method of obtaining stock for shellfish farms. Moreover, it does not allow for scaling-up farms. The women shellfish farmers in Zanzibar are at the point where scaling up would be possible if greater numbers of juvenile bivalves were available. Previous pilot spat collection studies helped identify several areas where spat fall may be high enough to support shellfish farms. This work will build on the preliminary efforts to conduct a one-year trial to confirm that these locations are adequate in terms of spat settlement rates and to elucidate annual patterns of spat settlement.

Quantified Anticipated Benefits

Quantifiable benefits will include: amount of spat collected, number of students and technicians trained, development of feasible spat collection methods, increased availability of information and increased interest in culture of native species.

Metrics

Number of institutions directly or indirectly benefiting from the training: 6
Number of individual participants in extension and technical training: estimated at 60
Number of communities benefiting from training: 8
Number of private businesses (including cooperatives and women's groups) benefiting from improved extension services: 10
Students involved: 2
Training modules produced: 1
CRSP newsletter articles: 1
Peer-reviewed journal article: 1

Activity Plan

Pilot studies in 2009-2010 assisted in locating several sites near the villages of Bwelo and Nyamanzi on the Fumba Pennisula of Zanzibar where spat settlement rates on artificial collectors were relatively high. Bewelo and Nyamanzi were among eight villages participating in previous bivalve and pearl culture development work and their residents were among the most active in the participatory research. Approximately 200 women on the Fumba Pennisula have participated or benefitted from past aquaculture development efforts. Similar experiments were also conduct near Tanga on the Eastern Coast of Tanzania and showed promising results. Improvement of spat collection methods will have regional benefits.

Spat collection experiments will be conducted by establishing submerged long lines in two areas and deploying 50 spat collectors every month over a one year period. Three different spat collection materials will also be tested. This will allow researchers to determine the best time of year to deploy collectors and which material results in the highest level of spat settlement. The latter is more complex than it may appear as results from spat collection for pearl oysters in the Pacific suggest that while many materials appear to be suitable in terms of the initial spat collection rate, some types may result in juveniles detaching themselves or being more vulnerable to predation. Collectors will be inspected two months after deployment to obtain an estimate of the number of juvenile bivalves which have attached and to identify these by species. Four months after deployment, the collectors will be removed from the water and all adhering bivalves counted and identified. The juveniles produced in this manner will be used in the nursery experiments. Two types of cages will be tested to determine which results in the highest survival and growth of juvenile bivalves. Data on water quality (temperature, salinity, turbidity) will be collected at each experimental site.Women from the two communities will participate in all aspects of this work and will be trained in the technical details of spat collection and nursery rearing.

Statistical Analysis

Analyses will be performed using the Statistical Package for the Social Sciences Version 10.1 (SPSS 10.1). Data on spat collection rates and survival will be tested by month and by the type of the collection material used. Data from the nursery trial will be tested to determine which cage type may result in higher survival and growth. In all cases, significant results will be followed by a comparison of means using the Least Significant Difference (LSD) Test. Normality and homogeneity of variance tests will be performed on raw data. Sample distributions violating assumptions will be log-transformed before analysis. Data, expressed as percentages, will be arc sine-transformed before analysis. All differences will be regarded as significant at $P < 0.05$.

Schedule

Work will start in July 2013 with establishment of the long-lines and procurement of other materials. Spat collectors will be deployed in August 2013 and continued through July 2014. Nursery trials will begin four months after the first juveniles are removed from the collectors; this is expected to occur in December 2013 or January 2014.

REPRODUCTION AND SEED PRODUCTION OF SAHAR (*TOR PUTITORA*) IN CHITWAN, NEPAL

Quality Seedstock Development/Study/13QSD02UM

Collaborating Institutions and Lead Investigators

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Agricultural and Forestry University (Nepal)	Dr. Madhav Shrestha
Fisheries Research Center, NARC (Nepal)	Jay Dev Bista
	C.N.R. Yadav

Objectives

1. To extend sahar breeding technology to Chitwan from work done in Pokhara;
2.To develop protocols for sahar reproduction and mass scale seed production in Chitwan;
3. To establish nursing and rearing management practices of sahar fry in Chitwan; and
4. To make sahar fry available for culture and restocking.

Significance

Sahar (*Tor putitora*) is an economically important, high-value indigenous fish species in Nepal (Rai et al., 1997). The price of sahar in the Nepalese market is almost double, compared to the commonly cultivated carps and tilapia species. Sahar is still taken in capture fisheries in lakes and rivers, but no commercial cultivation has begun in Nepal. This species is declining from its natural habitat mainly due to urbanization, illegal encroachment, over-fishing, and ecological alterations of physical, chemical, and biological conditions in the natural environment (Bista et al., 2008).

Various national aquaculture plans for Nepal, most recently NARC (2010) and FAO (2013), have included the development of cold water systems for aquaculture in upland areas as a priority. In addition, seed production is also recognized as a major bottleneck to aquaculture development in Nepal. The potential culture systems for cool water areas include development of trout culture from imported fish, as well as the use of indigenous fish like sahar for aquaculture. Culture of indigenous species is a high priority globally, as it reduces issues with invasive species introductions, is in harmony with local cultural needs, and increases the possible options for aquaculture production. This proposal seeks to produce large volumes of sahar seed, as well as develop nursing and rearing techniques, so that sahar culture can be extended from experimental farms to more commercial systems.

Attempts to culture and conserve this species have been initiated in Nepal with major efforts to develop culture technology and propagate the species (Gurung et al., 2001; Joshi et al., 2002). This has led to a better knowledge of spawning biology, ecology, and behavior of sahar, as well as preliminary growth performance in captive conditions. Enhanced growth in tropical and subtropical ponds, as well as the recent breeding success in hatcheries, has raised new hopes on the prospects of sahar aquaculture in Nepal (Shrestha et al., 2005, 2007; Bista et al., 2001, 2007; Rai, 2008). In addition to culture of fish to adult size for consumption, these new developments can contribute to rearing individuals that can be stocked into natural waters to replenish populations there, helping to halt the decline of this native species. Due to its omnivorous and predatory feeding, sahar has also proved to be a good candidate to co-culture with mixed-sex tilapia to control tilapia recruits in a pond and provide better size at harvest and yield of tilapia (Shrestha et al., 2011). Inclusion of sahar in polyculture of mixed-sex tilapia with carps has enhanced production in these ponds (Jaiswal, 2012).

Sahar is known to be an intermittent in spawning behavior. It can spawn in most months, except January, under cultured conditions, but in natural waters, it spawns during the monsoon when rivers and streams are at peak flow. Sahar typically migrate a long distance from large rivers to streams for spawning. The Fisheries Research Center in Pokhara is the only location where fry are produced, and this production is still in limited quantity. Demand for sahar fry has increased for restocking in rivers and lakes, as well as for aquaculture production. Lack of availability of fish seed is a major bottleneck for commercial production and conservation. Sahar breeding has been attempted in the Aquaculture and Fisheries Department of AFU in Rampur, Chitwan and was successful in producing 250 fry during a practical class in 2010.

This study is intended to transfer and develop the breeding technology, nursing, and fry production developed in the subtropical and tropical climate of Pokhara to other sites in Nepal in order to increase availability of sahar fry for culture.

Quantified Anticipated Benefits

The results of this study will delineate methods to produce sahar fry for restocking in rivers and lakes where populations have decreased, and will provide an additional fry for polyculture systems of Nepal. In Nepal, government labs have initiated fry production for most species, then trained residents to produce fry for larger scale commercial use. We expect to initiate seed production at the new site in Rampur, and as a result, we should produce several thousand fry. The promotion of this indigenous fish will increase pond productivity, harvest, and income. We anticipate at least five farms using sahar in their polyculture systems when seed becomes available, as it will add a highly valued fish into the culture system that will supplement income. Availability of cultured sahar for restocking should help to reverse population declines in natural waters. We expect to stock fry in at least five different natural waters as a result of our seed production. Fry production will also benefit fish culturists in other countries where sahar is native. For Nepal, we intend to initiate outreach on production of sahar seed by running at least one workshop on our methods and results. Through this, we intend to train at least 20 farmers in the technology and aim for at least half of them being women.

Deliverables

One workshop with 20 farmers on sahar seed production. One report clarifying sahar production techniques.

Research Design

Location

- The Fisheries Research Center in Pokhara will serve as a reference site, with the Aquaculture Department Farm of AFU at Rampur, Chitwan as the new working site.

Methods

- Mature brood stock (1000 g size or larger) will be collected and maintained in Pokhara and Chitwan.
- Pond facilities: 1 brood pond in Pokhara; and 3 earthen ponds of 200 m^2 will be used in Chitwan.
- Culture period: One year for mature brood maintenance and breeding.
- Nutrient input: Daily feeding with locally made feed containing 35% protein at 2-3% BW.
- Water management: maintain at 1.5 m deep or more. Water quality monitoring will be done using standard protocols, with monthly water sampling.
- We should hold over 600 sahar for broodstock development in Chitwan. We will monitor oocyte development (using cannulation on a subsample of about 10 fish per month), gonadosomatic index (GSI of fish that are stripped of eggs at maturation), and egg somatic index (ESI for these same fish). Temperature and other conditions will be monitored over the brooding period.
- Seasonal maturation patterns will be determined February to March and September to November.
- Egg incubation systems will be developed. We anticipate using hatching jars for incubation, although we may also try Heath trays.
- Fingerlings will be reared in outdoor ponds, first by promoting natural feeds with fertilizer in the ponds, later using supplemental feed after fry have been successfully weaned.

- Growth will be estimated over one year, with monthly sampling of fish size and apparent health for fingerlings raised in ponds.

Statistical design

- Performance of sahar breeding (ESI, GSI, Maturation patterns) will be compared between Pokhara and Chitwan hatcheries.
- Growth and survival of sahar fry and fingerlings will be compared between the two locations

Null hypothesis

- There are no differences in breeding and growth performance of sahar between the two locations (climatic conditions)
- Statistical analysis: ANOVA or T-test as appropriate.

Schedule

Broodstock collection and maintenance will begin 1 October 2013, fry rearing is planned to occur from November 2013 through December 2014. Final report will be completed no later than 30 September 2015.

TOPIC AREA

HUMAN NUTRITION AND HUMAN HEALTH IMPACTS OF AQUACULTURE

❖

INTEGRATED *MOLA* FISH AND GHER/FRESHWATER PRAWN FARMING WITH DYKE CROPPING TO INCREASE HOUSEHOLD NUTRITION AND EARNINGS FOR RURAL FARMERS IN SOUTHWEST BANGLADESH

Human Nutrition and Human Health Impacts of Aquaculture/Experiment/13HHI03NC

Collaborating Institutions and Lead Investigators

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	Ms. Sadika Haque
Khulna University (Bangladesh)	Sk. Md. Bazlur Rahaman
University of Dhaka (Bangladesh)	Abu Torab M. A. Rahim
WorldFish (Bangladesh)	Manjurul Karim
North Carolina State University (USA)	Russell Borski

Objectives

1. Evaluate production potentials of Mola fish (Amblypharyngodon mola) integrated with existing practices of gher - prawn and gher - prawn/carp farming systems.
2. Better identify Mola stocking densities for gher- prawn/carp polyculture to generate increased production yields.
3. Evaluate the potential use of gher/pond mud as fertilizer for growing vegetables on gher/pond dykes.
4. Assess the nutritional benefits and economic returns of the households practicing integrated aquaculture (15 households)

Significance

The wide-spread use of integrated farming practices, including but not restricted to the production of multiple finfish, holds significant promise for increasing dietary nutrition, productivity, and profitability of farming households in rural Bangladesh (Lightfoot *et al.,* 1990). Currently, rice and fish comprise the main diet of low-income families, particularly during the production season for these crops (Roos *et al*., 2007). Although integration of freshwater prawn (*Macrobrachium rosenbergii*) farming in seasonal rice /paddy fields (*ghers*) has been successfully implemented and serves as a significant source of income to coastal families, farmers typically sell the prawns produced to fetch higher prices in overseas markets, meanwhile family members (particularly women and children) remain malnourished from lack of complete protein, vitamins, and other minerals in their diet. The present investigation proposes to address this problem by incorporating additional crops (*Mola* fish, and vegetables) into current gher-prawn farming practices. As *Mola* fish and fresh vegetables are highly nutritional crops, but have little potential for sale in cities or overseas markets, the cultivation of these foods will directly benefit local dietary needs. These studies will test novel integrated designs targeted specifically for increasing nutrition in low-income farming households of rural Bangladesh.

Successful adoption of integrated farming practices requires the designs to be tailored around existing agricultural practices. Currently, much of the land available for agriculture is restricted to rice production (10.1 million hectares), however seasonal water bodies (2.83 million hectares; flooded for 4-6 months) remain under-utilized and play an increasing role in the production of aquaculture crops (Kunda *et al.,* 2008). Negative social and environmental issues associated with cultivation of marine shrimp has made farming of freshwater prawns (*M.rosenbergii*) more attractive to local farmers (Johnson and Bueno, 2000; New, 2000). Currently, freshwater prawns are cultured in over 50,000 hectares in and around the Southern coastal regions of Bangladesh (DOF, 2012). As prawn culture is mostly produced in fallow rice fields flooded after harvest, there is a great potential for expansion of this practice throughout the country, if appropriate strategies are developed (Wahab *et al.*, 2012). While the widespread cultivation of freshwater prawns has opened new opportunities for higher income earnings for local farmers, these products are not consumed directly, but rather sold to overseas markets for fetch higher prices. The objectives of this project are to increase the culture of prawns in under-utilized gher/ponds throughout Southern Bangladesh, but also to promote their integration with other crops (both fish and vegetables), which are consumed directly by local households, thereby increasing both earning income (from prawn sales) and dietary nutrition (side crops-fish and vegetables) available to rural families. The inclusion of other fish species (*e.g*., *Mola* and *Rohu*) could also increase prawn production yields, as combining species of different trophic levels could maximize nutrient utilization and decrease the potential for harmful phytoplankton blooms, which cause mortality by decreasing dissolved oxygen levels (Halver, 1984; Wahab *et al*., 2008). Therefore, efforts will be made to identify a suitable stocking density for *Mola* (*Amblypharyngodon mola*) for maximum nutrient utilization and prawn production through harnessing synergistic effects.

Child malnutrition continues to be major public health problem in rural Bangladesh. Up to 38% of all pre-school children have vitamin A deficiency, with up to 55 percent exhibiting signs of iron-deficient anemia (Micronutrient Initiative/UNICEF, 2004; West, 2002). These effects may be alleviated, in part, through consumption of small indigenous fishes, such as *Mola*, which have significantly higher concentration of vitamin A (~1900 IU, Thilsted *et al*. 1996) and micronutrient content than other commonly consumed fishes (*e.g*. carp). The *Mola*, a fish from 12-15 cm in length with soft bones, is particularly favored in the diets of many people; however consumption is limited to those captured in local rice fields, rivers, and canals. Early experiments suggest that *Mola* can be successfully cultivated in the presence of other finfish cultivars (e.g., carp; Alim *et al*. 2004; Kadir *et al.* 2007; Wahab *et al*., 2003). These fish are self-recruiting species, existing naturally in perennial ponds and other freshwater sources. Once stocked, *Mola* can reproduce within the ghers or in drainage ponds and can be continuously harvested over the production cycle of carp or prawn allowing for home consumption. *Mola* feed primarily on phytoplankton and detritus, therefore no feed input are necessary. Moreover, their bacteria-enriched waste can be utilized to enhance prawn production.

In this investigation, we propose to integrate *Mola* cultivation with prawn farming, where prawns can continue to be sold as a cash crop to increase income earnings while *Mola* could directly meet household nutritional needs. Additionally, we propose to utilize nutrient-rich mud, a byproduct of gher-prawn farming, to fertilize the unflooded spaces (dykes) between rice ponds for better vegetable cultivation. Pond muds from carp and tilapia production have proved to be potent fertilizer for the cultivation of seasonal vegetables in Northern Bangladesh (Wahab *et al*., 2001), however this method has not been developed for prawn culture. We propose to examine the soil nutritive value of gher-prawn mud and its utility for the cultivation of fresh produce (*e.g.*, tomatoes, spinach, gourds). The consumption of *Mola* and fresh vegetables will significantly enhance the diet of farming households and help to alleviate common nutrient deficiencies observed in pre-school children and women of rural communities.

Quantified Anticipated Benefits

1. Successful cultivation of nutrient-rich *Mola* for family consumption will increase the dietary nutrition available for low-income farming households.
2. We anticipate that integrated production of both prawns and *Mola* will lead to higher production yields for both crops, generating better economic returns for the farming households.
3. Twenty-five participating households will receive direct, on-site instruction on the benefits of using integrated farming designs. If successful, this training will be critical for further promotion of

integrated farming practices in other villages.

4. The integration of vegetable farming on "prawn-*Mola*" dykes is a novel approach to providing better nutrition as both *Mola* and fresh vegetables will increase the availability of vitamin A and other micronutrients currently lacking in the diet of women and children.
5. Efficient use of gher-prawn mud after each prawn culture cycle will enhance nutrient utilization and decrease negative environmental impacts associated with nutrient loading.

Plan of Work

Location

This investigation consists of a series of four studies, which will be carried out on participating farms located in villages near Dumuria Upazila, Khulna District, Bangladesh. Water quality, and soil nutrient analyses will be performed at Khulna University and BAU, Mymensingh, Bangladesh. The nutritional benefits and economic returns will be analyzed by Dr. Rahim (Institute of Nutrition and Food Science, Dhaka University) and Ms. Sadika Haque, an Agricultural Economist from the BAU, Mymensingh.

Methods

1. Evaluate production yields of Mola (*Amblypharyngodon Mola*) integrated with existing practices of gher-prawn and gher-prawn/carp production in Bangladesh

This study will evaluate the feasibility of adding nutrient-rich *Mola* (*A. Mola*) to current gher-rice culture of prawns, and within polyculture of both prawns and *Rohu* carp (*Labeo rohita*) at the Solua/ Ramkrishnapur village (Dumuria, Khulna District). The inclusion of *Rohu* carp in our design follows observations that local growers will occasionally incorporate carp species with prawn culture as an additional crop (Wahab *et al.*, 2012), therefore *Mola* production should also be evaluated within this context. Fifteen gher-ponds of similar size (< 1 ha) and depth (1.0) will be used for this study, using the design and stocking densities as below:

Parameter/Stocking Density	Treatment 1	Treatment 2	Treatment 3
Prawns (*M. rosenbergii*)	$3/m^2$	$3/m^2$	$3/m^2$
Mola (*A. mola*)	none	$2.5/m^2$	$2.5/m^2$
Rohu (*L. rohita*)	none	none	$0.5/m^2$
Replicate gher ponds (*n*)	5	5	5

Ponds (N=15) will be limed and fertilized prior to filling with water and stocking in accordance with local farming practices. Water quality will be monitored daily on-site using dissolved O_2 meters and secchi-disk depth, with additional parameters (e.g. ammonia, nitrites, nitrates, phosphates, total nitrogen and total phosphate) measured weekly at Khulna University. During the 5-month grow-out period, performance data (weights/lengths) for all species will be collected by monthly sub-sampling, followed by total yield assessment at the end of study. Significant differences ($p < 0.05$) in water quality, total production yields (biomass), and prawn, *Mola* and carp production yields/growth will be determined by ANOVA using SPSS.

Null Hypothesis: The addition of Mola to existing gher-prawn culture yields has no differences in the total production yield of prawns and/or carp (total biomass).

2. Improving *Mola* stocking densities for gher-prawn/carp polyculture to generate higher production yields

This study will assess whether increasing *Mola* density can improve production yields without negatively impacting the culture of prawns or *Rohu* carp. Based on the data obtained from Study 1, specifically if the outcome of including *Rohu* with prawn-*Mola* production is positive, we will then improve stocking density for *Mola*. Since *Rohu* carp is a fast growing cultivar, feeding on zooplankton and phytoplankton, it may occupy a trophic level niche not utilized by current farming practices, and therefore this implementation could significantly increase total production yield. As our primary objective is the incorporation of *Mola* into prawn/carp production, we will hold the stocking density of *Rohu* constant ($0.5/m^2$) due to limited pond availability for the present study. A more suitable stocking density for *Mola* will be determined using the following experimental design:

Parameter/Stocking Density	*Treatment 1*	*Treatment 2*	*Treatment 3*	*Treatment 4*
Prawns (*M. rosenbergii*)	$3.0\ /m^2$	$3.0/\ m^2$	$3.0/m^2$	$3.0/m^2$
Rohu (*L. rohita*)	$0.5/m^2$	$0.5/m^2$	$0.5/m^2$	$0.5/m^2$
Mola (*A. mola*)	None	$2.5/m^2$	$5.0/m^2$	$10.0/m^2$
Replicate gher ponds (*n*)	5	5	5	5

Ponds (N=20) will be limed and fertilized before stocking in accordance with current gher-rice farming practices. Water quality data and growth parameters will be collected as stated previously (see Study 1). ANOVA will be used to determine significant effects ($p < 0.05$ in water quality, total biomass, and specific production yields by treatment group.

Null Hypothesis: No differences in total production of yields for prawn and carp occur with varying the Mola stocking densities.

3. Evaluate the potential use of gher/pond mud for growing vegetable on gher/pond dykes.

This study will evaluate whether bottom mud from gher-pond/prawn culture can be utilized as nutrient-rich fertilizer for enhancing household production and consumption of fresh vegetables. Currently land holdings for most farmers in Bangladesh are allocated for gher-pond rice and prawn production, with little remains for household cultivation of fruits and vegetables. This investigation will explore the nutrient composition of gher/pond mud (nutrient contents and organic matter from prawn farming) and evaluate the potential for growing common vegetables using gher/pond dykes. The benefits of using gher/pond mud will be tested on three commonly grown vegetables with the following factorial design: treatments (2; dyke plots with or without addition of mud [control]) X vegetable type (3; tomato, spinach, and pointed-gourd [*Potol*]) X replicates (3 per treatment/vegetable type).

Each of the plot size for all treatments will be 9 m^2. These plots will be distributed onto 15-18 practicing farms near Dumuria Upazila village (Khulna District) to observe between pond variations. For the treatment plots, gher-pond mud of similar volume will be collected and spread on the dykes after prawn harvest. Watering to the vegetable plots will be done from available water sources nearby, not from pond water. Leafy vegetables will be harvested from treatment and control plots on the same days, with fresh weight biomass determined for all groups. Other vegetables, such as tomatoes, will be harvested when ripe and total yield will be recorded as they are collected and consumed. A record book will be maintained by the woman of each practicing household for collection of data.

Plant length, leaf size, and general plant health will also be assessed. Assistance from a horticulturist will be sought for measurement of plant growth and production. Soil nutrient and physical composition (soil type, organic matter, total nitrogen) analyses will be performed by the BAU Dept. of Soil Science Laboratory. Significant effects of gher-pond mud treatment on crop productivity will be determined by 2-way ANOVA. We will also test if differences in vegetable yield between treatment (pond mud) and control (dyke soil) may be associated with differences in soil chemistry within and among site locales.

Dyke farming expert, Manjurul Karim of WorldFish will assist in site selection and implementation of the pond-dyke cropping study. Their secondary data collected over the years in this region will aid in site selection. WorldFish is interested in up-scaling this activity within the Southwest of Bangladesh, subject to the successful outcomes of these investigations, and hence will participate at no cost to the project. They will also participate in the AquaFish Innovative Lab Project Workshop, to be held at the end of the

project, and will disseminate technologies from this and other investigations.
Null Hypothesis: No differences in vegetable crop yields are achieved with the use of gher-pond mud as a nutrient supplement.

4. Assess the nutritional benefits and economic return for households practicing integrated aquaculture
We will evaluate the perceived economic and nutritional benefits to the users of our integrated gher-prawn/*Mola* and gher-prawn/dyke cropping designs through survey questionnaires of 30 households (Dr. Rahim, Institute of Nutrition and Food Science, Dhaka University), evaluating 15 participating and non-participating families. A 5-day recall test (Roos et al., 2007) will be employed to interview family members of sub-sampled households, to collect basic information on diet and food consumption (fish and vegetable, along with rice), and whether they feel that adoption of these methods can significantly improve nutritional needs in their homes (qualitative ranking 1-5). Surveyed households will be selected on the criteria of equivalent economic status and small land holdings (<1 ha). A supplementary questionnaire, in consultation with agricultural economist Sadika Haque (BAU), will also be given concerning questions of input costs, sale proceeds (prawn, finfish, vegetables), to be divided based on current farming practices.

Schedule
July – Nov 2013: Study 1 completed
Jun 2014 – Oct 2014: Conduct studies 2 and 3
April – Aug 2015: Conduct study 4 and Final Technical Report

Deliverables
1. Cultivation of New Crops for Home Consumption – Studies 1-3 will report the total production yield (kg) of *Mola* fish and fresh vegetables targeted for home consumption. We anticipate successful cultivation of these crops in combination with gher-prawn/carp farming. The estimated monetary value for fresh vegetables will also be reported (Study 3).
2. Improvements in Human Nutrition – We anticipate the production of both *Mola* and fresh vegetables will improve dietary consumption of micronutrients for rural farming households, since both crops possess high nutrient content, including for vitamin A. Benefits to human nutrition will be documented through a perceived benefits survey.
3. Improvements in cash crop production and market return – The total production yields and estimated market returns for both prawns and carp (*Rohu*) will be reported for Studies 1-3. We anticipate equal or greater production yields/market return for prawns and *Rohu*. Improvements in production yield may occur through better nutrient utilization and improved water quality (assessed as in Investigations 1, 2, 3, and 5). Perceived economic benefits will also be documented in Study 4.
4. Documentation and Dissemination – The findings from these studies will be reported through the Technical Reports of the AquaFish Innovation Lab, presentations through the AquaFish Innovative Lab Project Workshop, the World Aquaculture Society, and peer-reviewed literature (1-2 manuscripts). Study 3 (dyke-cropping) will be performed in coordination with WorldFish (Dr. M. Karim) for consideration of future expansion of this project. Approximately 15-20 farming households will receive direct training on the effectiveness of gher-prawn/*Mola* or gher-prawn/dyke cropping in the proposed studies.

ENHANCING FOOD SECURITY AND HOUSEHOLD NUTRITION VULNERABILITY OF WOMEN AND CHILDREN FOCUS ON NUTRIENT DENSE COMMONLY CONSUMED FISH FROM CAPTURE FISH AND AQUACULTURE IN CAMBODIA

Human Nutrition and Human Health Impacts of Aquaculture/Activity/13HHI02UC

Collaborating Institutions and Lead Investigators

University of Connecticut-Avery Point (USA) — Dr. Robert Pomeroy

Inland Fisheries Research and Development Institute (IFReD) (Cambodia) — Dr So Nam, Mr. Chheng Phen, Mr. Touch Bungthang

Objective

The objective of this investigation is to enhance the food and nutrition security of women and children through nutrient dense of commonly consumed fish and other aquatic animals (OAAs), aquaculture and its products: nutrient dense of these foods, improving traditional processing technology and trade to address malnutrition of vulnerable women and children.

Significance

Population growth, and other changing variables such rainfall, sedimentation, salinity, human activities are said to be affected to the fish production, livelihood opportunity, food security, nutrition and its implication to health.

The fish and aquatic animals (frog, crabs, snails and shrimp) is the second largest staple foods for Cambodian people, contributes about 75 percent of animal protein intake. They have formed as integral part of the diet of many rural Cambodians. Poorer households in particular, with little alternative food production capacity, turn to such sources not only for additional food for themselves as source of their food security, but also for their daily nutritional requirement and for sale to earn income, food and nutrition security. It is reported that these foods have high nutrient content and high bioavailability of micronutrients, particularly small indigenous fish species.

The application of traditional food processing/preservation technologies in Cambodia dates back in the ancient times and these techniques are often used, especially fish (fermented fish, salted, smoked, fish sauces, and fish paste called "Prohoc". These uphold the Cambodian cultural identity. Fish processing provides many with a continuous source of protein throughout the year. Moreover, the fermentation process of some foods have potential to improve its nutritional qualities, reduce anti-nutrients, decrease pH, increase minerals and provide potential pro-biotic effects through lactic acid bacteria.
The availability of fish and aquatic products in Cambodia should normally be adequate for a balanced diet, but productive capacity or purchasing power of many households is limited, and in these circumstances the diet become more restricted to fish. Trade and market impacts in production levels is said to be changed throughout the value chain such as reduced trade volume and values reduced export earning and reduced livelihood opportunity and increasing malnutrition.

The prevalence of malnutrition among preschool children continues to be a major problem in Cambodia. According to The National Health Statistics of Cambodia 2000 reports that 23% of babies were born with a low birth weight <2500 g. The CDHS survey also found that 21% of mothers had a BMI below the cut-off of 18.5, indicating chronic energy deficiency. The CDHS 2000 indicated a high level of protein/energy malnutrition among children under five years of age, with a stunting prevalence rate of 44.3% (severe stunting -3SD, 20.2%). The prevalence of wasting was 15.0% (severe wasting -3SD, 3.8%) and the prevalence of underweight was 45.3% (severe underweight -3SD, 12.5%).

The CDHS 2000 showed an overall 63% rate of anemia among children of 6-59 months. Children under two years were more likely to be anemic than older children. A high prevalence of anemia (90%) was found in the age group 10-11 months, an indication of poor complementary feeding practices. In addition, 58% of non-pregnant women and 66% of pregnant women were classified as anemic

The First National Goiter Survey was completed in 1997 and estimated a national total goiter rate of about 12% in the 8-12 age group, with a rate of 45% in some areas. The survey recorded a total goiter rate of 17% in a sample of over 35 000 children. Results from the Cambodia National Micronutrient Survey 2000 show that vitamin A deficiency is still a problem of public health significance. The prevalence of night blindness among children aged 18-59 months was above the WHO cut-off (1%) in seven of the 10 provinces included in the survey, as well as among the lactating mothers (range: 1.1-6.8% in the 10 provinces) and during the mother's most recent pregnancy (range: 2.0-9.3%). The survey also showed that vitamin A intake was very low, with less than 10% of women and children meeting their recommended daily intake.

There is a lack of documentation on the commonly consumed traditional food items, traditional food processing technologies, and information on nutrient contents of these food groups. At the same time, the needs for improve product quality, hygiene, sanitation, the appropriate technologies, value change, and trade are also crucial.

Quantified Anticipated Benefits

1. Two Master students will be involved in this investigation. Their involvement in assisting the project preparation, survey design, data encoding, data analysis, and report writing.
2. At least 10IFReDIstaffs will be involved in survey such as data collection, training activities.
3. At least 500IFReDI/FiA staff, scientists, researchers, government officers and managers, and NGOs in Cambodia will be participated in series of consultation meeting and workshop on the impacts of mainstream dams on the Mekong River system and climate change on fish yields for snakehead and small-sized fish, and the impacts of changes in fish yield on fish consumption and food security in Cambodia, especially by women and children and in proposing the recommend adaption options and strategies for women.
4. At least 300 women in fisheries and aquaculture households in Cambodia will be better informed and have better information on current and potential impacts of climate and non-climate drivers of change on aquaculture and fisheries and corresponding adaptation strategies.
5. Many others in the Mekong region will benefits from this project through sharing of research findings.
6. This investigation will provide a return benefit to the US by allowing the Lead PI to expand his work in SE Asia on food security and fisheries and aquaculture and return this knowledge and information to graduate students at the University of Connecticut.

Research Design and Activity Plan

The following activities are proposed to implement this study in order to achieve the above objectives:

Activity 1.

- To identify commonly consumed-fish and other aquatic resources, aquaculture and its products in Cambodia.
- The study will employ both primary and secondary data gathering. Primary data will obtain through field surveys by interview key informant interviews (KII), and focus group discussion (FGD). Secondary data will obtain from journals, reports, books, and other materials will collect from relevant offices, NGOs, and websites.
- Information about fish species and other aquatic animals (OAAS) based on availability, utilization, and perception of people. KII will be conducted with sellers, middle vendors, the elderly, hunters, and farmers from the different ecological zones in Cambodia. Locations include: Stung Treng in the upper

portion of the Greater Mekong Basin; Siem Reap/KampongThom, located in Tonle Sap Lake; and Prey Veng located in the Lower Mekong Basin.

Sample size
The total number of respondents was determined based on Slovin's equation as shown below:

$$n = \frac{N}{1 + Ne^2}$$

Where n = a sample size
N = total population size from three villages
e = allowable error of ten percent (10%).

Questionnaires
Questionnaires will be formulated prior to the start of the fieldwork. The interviewers will undergo training on survey questionnaires. Each enumerator will be given a bag, notebook, pencils, etc. Training will be conducted by PIs.

Pilot Testing
Pilot testing of the questionnaires will be done in one selected commune for two to three days at suitable sites, which will be sent to the village head informing him of the conduct of the survey. A face-to-face interview with head of the family/the household members will be done. Relevant or additional information that will be gathered should be written immediately on the questionnaire. At the end of the interview, questionnaires will be cross-checked by members of the team survey for any missing record or information. The final draft of the questionnaires will be thoroughly discussed to ensure the same understanding of the questionnaires. This will be immediately followed by database entry.

Survey
Letters to the village authorities informing them of the conduct of the survey will be sent at least 1 week before the actual survey. The survey will be conducted face-to-face interview with the formulated questionnaire and focus group discussion.

Activity 2.
To determine the nutritional composition of nutrient dense identified commonly consumed-fish and other aquatic resources by women and children with focus on key micronutrients such as iron, zinc, vitamin A and macronutrients (protein and fat). Samples of selected commonly consumed fish species and OAAs will be collected fresh from landing sites, local markets, fishermen, and farmers for nutrient analyses. Subsamples of raw, cleaned parts will be obtained by having village women clean the fish according to their traditional practices. Vitamin A compounds (all transretinol, 13-cis retinol, all-trans 3,4-dehydroretinol, 13-cis 3,4-dehydroretinol, and b-carotene) in fish samples will be analyzed using high-performance liquid chromatography. Calcium, iron, and zinc will be determined by atomic absorption spectrometry. The content of nonheme iron will be determined by the widely used ferrozine colorometric method. Heme iron and complex-bound non-heme iron will be calculated as the difference between total iron and inorganic iron. The analysis will be conducted at Mahidol University in Thailand, the National Council for Nutrition in Vietnam, or in the United States.

Activity 3.
- Analysis of recommend policy strategy for women and children
- A series of consultations and final workshop will be conducted based on both outputs
- Activities 1 and 2 will cope up with the recommended adaption option and strategies for women and children

- The appropriate communication products will be developed:
  - Investigation finding report in English
  - PDF file of Investigation finding report in English which can access through web, and
  - 1500 factsheets of investigation report in English and Khmer.
- Undertake activities to disseminate the communication products and promote the uptake of the study findings (e.g. meetings, workshops, mail communication products, etc.).

Location of work

Inland Fisheries and Development Institute (IFReDI), Phnom Penh, Cambodia. The field activities will be undertaken in Upstream Mekong (Sambor, Kratie Province), Downstream Mekong (PoeumRour, Prey Veng province), and the Tonle Sap area: (Kampong Kreang, Siem Reap and PhatSand, Kampong Thom province).

Methods

The project activities are organized using a systematic, stepwise approach from collection of information on utilized foods to rigorous testing of nutrients bioavailability and efficiency, followed by promotion and dissemination of the results and development of generic recommendation policy. The activities are conducted by a multi-disciplinary research team using appropriate quantitative and qualitative research methods.

Schedule

See activity table on the following page.

Deliverables

- Investigation finding report in English which can be accessed through the Web
- 1500 factsheets based on the investigation report in English and Khmer

Activities	Sub-activities	Who	Yr	2013			2014												2015								
			Mo	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1. Project Design, Management and design	Review project document	PI		x	x																							
	Project financial arrangement	PI		x	x																							
2. To identify commonly consumed-fish and other aquatic resources by women and children in Cambodia.	1. Design survey	PI			x	x																						
	2. development, training, pilot testing, refinement of survey questionnaire	PI and Enumerator					x	x	x	x	x																	
	3. undertaken the survey	PI and Enumerator					x	x	x	x	x																	
	4. database development and training	PI/Database expert					x	x	x	x	x																	
	5. data encoding	Enumerator									x	x																
	6. data analysis	PI/Database expert										x	x	x														
	7 interpreting the result and report writing	PI											x	x														
3. To determine the nutritional composition of nutrient dense identifiedcom monly consumed-fish and other aquatic resources, aquaculture and its products.	1. Sample selection and preparation	PI													x	x												
	2. Conduct analysis	hiring expert														x	x											
	3. Interpreting the result and report writing	PI															x	x	x									
4. Analysis of recommend policy strategy for women and children	1. Consultation meeting workshop 1	PI																			x							
	2. Consultation meeting workshop 2	PI																			x							
	3. Consultation meeting workshop 3	PI																			x							
	4. Final workshop 1	PI																					x					
	5. Final workshop 2	PI																					x					
	6. Final workshop 3	PI																					x					
	7. Proposed the recommendation for adaption options and strategies for women	PI																							x	x		
	8. Develop and disseminate the communication products	PI																									x	x

ASSESSING THE NUTRITIONAL IMPACT OF AQUACULTURE POLICY IN FISH FARMING DISTRICTS IN TANZANIA AND GHANA

Human Nutrition and Human Health Impacts of Aquaculture/Study/13HHI01PU

Collaborating Institutions and Lead Investigators

Purdue University (USA)	Kwamena K. Quagrainie
Sokoine University of Agriculture (Tanzania)	Elibariki Emmanuel Msuya

Objectives

1. Assess improvements in household food security and nutrition in selected fish farming communities.
2. Measure the effect of aquaculture as an input and technology transfer program on household food security using nutritional indicators.

Significance

The Millennium Development Goals (MDGs) adopted by world's leaders at the Millennium Summit of the United Nations in 2000 sought to achieve peace and decent standards of living for every man, woman and child. The MDGs aim to eradicate extreme poverty and hunger, achieve universal primary education, promote gender equality and empower women, reduce child mortality improve maternal health, combat HIV/AIDS, malaria and other diseases, ensure environmental sustainability, and develop global partnerships for development. Tanzania and Ghana committed to the time-bound MDGs and the associated indicators.

Aquaculture is one of the world's fastest growing food production sectors with great potential for food supply, poverty alleviation and enhanced trade and economic benefits and has been recognized as such by the Ghanaian and Tanzanian governments. Fish farming has contributed towards poverty alleviation in poor societies in various areas of the world where it is traditionally practiced, e.g., Bangladesh (Jahan et al., 2010) and Nepal (Bhujel et al., 2008). Aquaculture development in Sub-Saharan Africa aims at improving food security and human nutrition; increasing domestic fish production; creating employment; promoting diversification and reducing risk; promoting economic development; and improving efficiency in the use of resources, especially water (Béné and Heck, 2005; Satia, 2011).

Aquaculture is considered an option for rural development because it provides an important opportunity to help solve problems of poverty, and protein malnutrition of the rural poor. Aquaculture expansion in Asian countries like Bangladesh and Thailand has led to enhanced food security among adopters and the population at large (De Silva and Davy, 2010; Jahan et al., 2010; Lazard et al., 2010). Bueno (2009) reported that the fish farmer's goal is often to produce the family animal protein food supply and sell part of the harvest for additional family income.

The Helen Keller International (HKI) established a direct linkage between agriculture and nutrition particularly for farmers and agricultural laborers from homestead food production in Bangladesh, Cambodia, Nepal, and the Philippines (HKI/Asia-Pacific 2001). The HKI program promoted small-scale production and consumption of micronutrient-rich crops and small animals, which resulted in vulnerable members of low-income households producing and consuming more micronutrient-rich foods and earning increased incomes from the sale of high-value products.

Tanzania's national development objectives for aquaculture include generating income for rural communities, increasing employment opportunities, improving rural quality of life, specifically through raising the living standards by improving food and nutritional security, and minimizing threats to food insecurity (URT, 1997). Improving food and nutritional security requires adequate food supply, and access to food by households from own production, the market or other sources, and the appropriate utilization of those foods to meet the dietary needs of the households. In Ghana, improvements in agricultural productivity have had positive impact on annual output of major staples and fish production from aquaculture. Total aquaculture production in Ghana has seen an increase from an estimated 4,500 mt in 2004 to 27,750 mt in 2012. Total production of fish from aquaculture in Ghana is available for domestic human consumption, thus improving human nutrition. Nevertheless, there are nutritional challenges, especially among children in both Ghana and Tanzania.

The focus of this study is to look beyond the direct production outcomes from fish farming in rural communities and consider the additional benefits that manifest themselves in nutritional outcomes. As the Tanzania and Ghana governments continue to implement its fisheries and aquaculture strategic plan, it is important to highlight nutritional impact assessments to ensure that the nutritional impacts of aquaculture development or for that matter, any new agricultural policy are accounted for in the implementation or intervention plans. Accounting for changes in nutritional outcomes is particularly relevant in Tanzania and Ghana given the efforts of the various governments to improve nutritional security.

Methodology

The anthropometric literature abounds with various indicators that measure nutrition-based food security. Anthropometrics is a means to measure human welfare in relation to changes in food supply and other development processes. To assess the nutritional impact of aquaculture in fish farming districts in Tanzania, it is necessary to identify variables in the literature that influence nutritional status. In developing countries the determinants of nutrition are multi-sectoral and interrelated, and include social and economic policies, the economic environment and ideological structures (Madise et al. 1999).

Individual characteristics as well as household and community variables are reported to help determine nutrition status. Individual level characteristics affect nutritional status as it is a reflection of dietary intake, illness, age, gender, size of baby at birth and whether the child is breastfed or not (Sahn and Alderman 1997; Madise et al. 1999; Chirwa and Ngalawa 2008). Household level characteristics such as the level of consumption and income; the gender and age of the household head; the age, educational and nutritional status of the mother; land size and the production of own food are reported to influence anthropometric outcomes (Quinn et al. 1990; Madise et al. 1999; Tharakan and Suchindran 1999; Chirwa and Ngalawa 2008). The nutritional value of the agricultural products is reported to determine the health status of the population (von Braun, 2007, Arole, 1999). Farm income and the income from agricultural labor are also reported to influence health in an indirect manner. National policies on social and economic issues also contribute to the nutritional outcomes of various populations (Madise et al. 1999).

Data and Analysis

We follow the anthropometric literature to assessing the nutritional impact of aquaculture policy in selected fish farming districts in Tanzania and Ghana. Data for the study will be obtained from two sources: Primary data through household surveys and secondary data from Tanzania's Household Budget Survey (HBS) and Ghana's Living Standards Survey (LSS). The primary data set will be cross-sectional data that comprises characteristics of communities and household level data from both aquaculture and non-aquaculture communities. The HBS and LSS collect information on a wide range of households and individual characteristics such as household members' education, economic activities, health status, household expenditure, consumption and income, ownership of assets and consumer goods, housing structure and building materials, distance to services and facilities and food security. Data are collected on several food item categories, which includes fish. In principle, nutrition consists of protein-energy nutrition and micronutrient enhancements. One measure to enhance protein-energy nutrition is to promote eating fish or seafood, reflected by the fish items consumed in the HBS and LSS databases.

In Tanzania, households will be selected from the southern highlands and northern highlands in districts where fish farming is predominantly practiced. Villages will be selected based on the intensity of aquaculture activities. Since HBS data include community characteristics, their effects will be controlled by complementing it with the information at the household level. In Ghana, households will be selected from the Ashanti and Brong-Ahafo regions where pond aquaculture is prevalent.

The quantitative assessment will be accomplished in two ways:
1. The use of Propensity-Score Matching (PSM) to estimate the effects of aquaculture development policies in selected communities. The PSM technique will use information from a pool of household units that do not participate in aquaculture to identify what would have happened to participating households in the absence of the aquaculture. By comparing how outcomes differ for participants relative to similar non-participants in aquaculture, it is possible to estimate the effects of aquaculture practices. The technique directly match participants with non-participants who have similar characteristics. Assignment to treatment will be nonrandom, and units receiving treatment and those excluded from treatment may differ in their treatment status and also in other characteristics that affect participation in aquaculture. To avoid these biases, the matching method will utilize a non-treated household that is similar to a participating household unit, allowing an estimate of aquaculture's impact as the difference between a participant and the matched comparison case and averaged across all participants. The approach will provide an estimate of the mean program impact for participants. The PSM technique has been applied in a very wide variety of fields in the program and policy evaluation literature (e.g., Dehejia and Wahba, 2002; Jalan and Ravallion, 2003; Galiani, Gertler and Schargrodsky, 2005; Trujillo, Portillo and Vernon, 2005).
2. Compare current primary data with secular trends reported in the HBS and LSS databases to assess nutritional impact through a correlation analysis and regression models which would include fish consumption, and whether or not households have participated in aquaculture and other aquaculture-related programs. The marginal health benefits to fish consumption and participation in aquaculture will be determined. A series of correlation regression models will be formulated to describe the relationships between fish consumption, and whether or not households have participated in aquaculture and selected household level characteristics such as the level of consumption and income; the gender and age of the household head; the age, educational and nutritional status of the mother; land size and the production of own food. These exogenous determinants have been reported to influence anthropometric outcomes (Quinn et al. 1990; Madise et al. 1999; Tharakan and Suchindran 1999; Chirwa and Ngalawa 2008). The regression models will assume assumption of random placement to minimize selection bias. However, where specific villages or communities were targeted for aquaculture programs and activities, non-random treatments will be adopted in the regression analysis.

Deliverables
1. Information on any relationships between household nutrition factors and participation in aquaculture activities.
2. Potential nutritional payoff or gains from national policy that encourages aquaculture technology transfer and adoption.
3. Indicator measures that capture aspects of aquaculture's impact on human nutrition and food security.
4. Outputs will include reports and peer-reviewed publications that will be made available to policy makers. These will be available online and in print.
5. Findings from the investigation will be presented at regional and international professional conferences.

Quantifiable Anticipated Benefits
1. Results will inform important policy decisions and implications on developing aquaculture in Tanzania and Ghana.
2. Documentation of metrics on aquaculture development and the effects on addressing food security and household welfare.

3. Aquaculture development will be viewed not only as improving food production and rural employment but also food security of households through improved nutrition.
4. US faculty will broaden their scope of knowledge from this study through the linkages of aquaculture policies with human nutrition. It will also assist researchers to look beyond the impact of policies on production to human nutrition.

Schedule

Data collection and collation	July - December 2013
Data Analysis	January - September 2014
Write up and Reporting	October - September 2015

ESTABLISHING SCHOOL PONDS FOR FISH FARMING AND EDUCATION TO IMPROVE HEALTH AND NUTRITION OF WOMEN AND CHILDREN IN RURAL NEPAL[3]

Human Nutrition and Human Health Impacts of Aquaculture/Activity/13HHI04UM

Collaborating Institutions and Lead Investigators

University of Michigan (USA)	James S. Diana
Agriculture and Forestry University (Nepal)	Madhav Shreshtha
	Dilip K. Jha

Objectives

1. To establish school ponds in villages for fish farming and education of school-age children on the value of household ponds; and
2. To develop women's fish farming groups at each school village to teach them about fish farming and household health.

Significance

Women play an integral role in the aquaculture and fisheries sectors all over the world. Even though women's roles and responsibilities are changing in some countries, there are constraints that limit female participation in aquaculture (Egna et. al., 2012). A few such constraints that women face in aquaculture and fisheries are: time availability and allocation, land ownership, and access to water, credit, training, and labor. Lack of training opportunities can trap women in vulnerable and poorly paid positions with no prospects of getting ahead (FAO, 1998).

Nepal has diverse agro-climatic and socio-economic characteristics but suffers from limited communication and transportation networks. Rural poverty is a key factor affecting food security. Undernutrition places children at an increased risk of morbidity and mortality and is also associated with impaired mental development. A report from the Nepal Demographic Health Survey found that 41% of Nepali children less than five are chronically malnourished and 11% are wasted (NDHS, 2011). This has declined slightly from 49% stunted and 13% wasted in 2006. Similarly, underweight children less than the age of five decreased from 39% to 29% from 2006 to 2011 (CBS, 2011).

Sadly, 85% of deaths among children less than five occur during the first year of life, and the overall infant mortality rate is 46 deaths per 1,000 live births. During infancy, the risk of neonatal deaths and post-neonatal deaths is 33 and 13 deaths per 1,000 live births, respectively (NDHS, 2011). These deaths are mostly attributed to diarrheal diseases, which can be exacerbated by undernutrition.

There is a global concern that nutritious food must be supplied to women as well as their children during the first 1000 days of life. Fish provides valuable nutrients to the world's population, including high-quality proteins (about 6% of world protein supply in 2002); balanced amino acids; vitamins A, D, and B12; iodine and selenium; and long chain omega-3 polyunsaturated fatty acids. Fish bones, when eaten, are also an excellent source of calcium, phosphorus, and fluorides (Jha, 2011; Jha and Jha, 2012).

Anemia has been a major problem in Nepal, especially among young children and pregnant women. It is prevalent mostly in rural areas, where nearly 47% of children and 36% of women have some degree of anemia. Overall, there has been very little improvement in the anemia status of children and women in Nepal since 2006 (USAID, 2011). The addition of animal source foods, such as fish rich in vitamin A, to

[3] Investigation conditionally accepted. The PI will submit a work plan change and IRB approval (or waiver) before work gets started on this investigation.

complement the typical Nepali diet should help stem the increase of anemia (Helen Keller Institute, 2002).

Most Nepalese live in rural areas at subsistence or near subsistence levels. Most of the protein consumed by the rural population comes from cereal grains. Cereal proteins are generally deficient in one or more essential amino acids and are not complete sources of proteins unless taken with other protein sources. An additional concern is that, in Nepal, people have a habit of consuming only one cereal grain at a time. People in Terai eat more rice, while those in the hills consume more corn. This tends to make their diets unbalanced in nutritional content. However, this diet may be made nutritionally superior by supplementing it with fish. For optimum human health, about 33% of total protein consumed should come from animal sources (AIT, 1994), but only 10% is from this source for the average person in Nepal. At least a three-fold increase in animal protein supply is required for optimum health of most rural people. Nepal should promote small-scale aquaculture by setting immediate and long-term objectives. The immediate need is to increase awareness among rural communities of the potential for backyard fish farming, while in the long-term, commercial aquaculture should be encouraged (Bhujel, 2012).

Aquaculture is a relatively new farming activity in Nepal, although a number of ethnic minority communities have traditionally made their living from capture fisheries. Integration of pond aquaculture into the existing crop- and livestock-based farming system is believed to be effective in increasing the local fish supply and diversifying livelihood options for small-scale farmers in the Terai and mid-hill valleys, thereby increasing the resilience of their livelihood (Shrestha et al., 2012). Increasing food and nutrition security, augmenting cash income for household expenses, and utilization of family labor are the major issues of the rural poor. Small-scale aquaculture has improved household food and nutrition security, income generation, and empowerment of women and marginalized communities. Fish has been considered “living cash” and a pond a “savings bank” because fish can usually be harvested throughout the year when needs arise (Bhujel et al., 2008; Shrestha, 2012). In a recent study carried out by University of Michigan student, Zachary Stepan, on nutrition and fish consumption among household fish farmers in the Chitwan and Nawalparasi districts, fish consumption was seasonal (due to cultural practice and beliefs) and that increased income was better correlated with improvements in nutrition rather than fish consumption (Stepan 2013). Based on these results, educational efforts will focus on timing of fish harvests, post-harvest practices, and other income generating activities for household farmers.

We propose to use school farms and education on the nutritional value and methods of aquaculture to help young people understand the value of fish production and consumption for their families. While many Nepalese attend school, most have only a primary school education and about 68% of women are illiterate. Therefore, training must consider these limitations while still providing for information exchange (Kloblen, 2011). Schools remain the center for learning in the community.

Having ponds in the schools will help disseminate a practical, hands-on message to the local population that fish are an important constituent to boost nutrition, and hence, residents will be encouraged to build a fish pond of their own. This will also help in capacity building of teachers who could spread knowledge of the importance of fish in nutrition to parents during teacher-parent interactions.; additionally, small-scale fish farming techniques and their connection to income generation and increased nutrition choices can be taught to future students and parents not presently enrolled or involved in the school. It will also educate students and adults on issues of environmental sustainability and nutrition. Finally, profit from the sale of fish will aid poor schools in developing infrastructure and covering daily expenses; part of this income associated with sales will go to long-term pond maintenance. In addition to the education of children, the school ponds can be used to train a group of women in each community on the methods of aquaculture and the value of fish consumption and income generation to their families. We plan to develop four women’s fish farming groups, one at each school to further extend fish farming information to local women. Since many of these women are illiterate, it will be necessary to develop special messages with clear visual and practical solutions to information exchange. The school ponds and practical training will be particularly effective in this information exchange.

The long-term sustainability of this project will be strengthened by the involvement of AFU faculty members that have a goal of such training and outreach to the public. Initial funding of the costs of pond construction and materials will be covered by this project, and we assume the ponds will bring income and support to the schools involved, so in the future only training will be needed to expand the program to additional schools. Also, continuance of the programs in the target schools should be enhanced by the income generated through the project.

Quantified Anticipated Benefits

The development of school ponds and women's fish farming groups will increase awareness of the value of nutrition and fish consumption in rural households by teaching school-age children and adult women about aquaculture. It will help generate income for the families and schools having ponds. It will also help in capacity building of teachers who could spread the knowledge on the importance of fish in nutrition to parents during teacher-parent interactions, now and in the future. We anticipate that at least 4 school ponds will be built, 40 or more students will be educated on the methods of fish farming, and 20 women will receive training in fish farming and its role in household health. This is based on a conservative assumption that only a small percentage of families will become involved in the school pond work, with an average of 10 students and 5 mothers per school. Of course, more may become involved in the program, although it will be an extracurricular activity. Our metric will be the number of people trained, and we will document that through record keeping at the schools. Success of this project will be assessed by surveys done in schools before and after the training, as well as evaluation of the consumption patterns of the households receiving training, again before and after the project is completed. The training will be considered successful if household consumption of fish increases by at least 20%, or if there is a significant difference in the knowledge on fish culture demonstrated by students and mothers participating in the training.

Deliverables

Training of 40+ students and 20 adult women through school pond programs at 4 schools. These numbers reflect trainees for this investigation and this time period only and do not account for the numbers of potential beneficiaries over time.

Research Design

Location of work

Public schools have not yet been selected but will be chosen from schools in Kathar and Kawasoti.

Methods

- A 200 m^2 pond will be constructed for two schools in each district.
- Carps and tilapia will be stocked in each pond and the materials necessary to grow them will be provided to each school system.
- School students and teachers will receive regular trainings about pond construction and farming activities, with similar lessons for both groups, at least at project initiation. Trainings will be open to all students regardless of age or gender. Students and teachers will be properly trained to be responsible for long-term maintenance, sales, and income generated from the school ponds.Focal educational activities include: fishpond construction; fish farming, including feeding, fertilizing, growing and handling fish; and nutrition education, including fish cooking and eating.
- Trainings of teachers and students will include managing pond depth, pond preparation, species choice, water color, fertilizing, feeding, growing, and harvesting of fish.
- Formal education activities will include fish pond construction, feeding, fertilizing, growing and handling fish, and nutrition education, including fish preparation and eating.

- Informal education activities include forming women's fish farming groups for each of the school ponds which will focus on nutrition education and income generating practices associated with fish consumption and farming.
- Biweekly meetings and discussions on fish farming will be held with four women's established at each of the target schools.
- Topics on fish farming will be extended, including managing pond depth, pond preparation, species choice, water color, fertilizing, feeding, growing, and harvesting of fish.
- Topics on health and nutrition will also be extended, including fish preparation and the value of regular fish consumption.
- As the project concludes, training of teachers and students at additional schools will be done by AFU faculty members, while the costs of new pond construction and materials will be borne by each school system adding to the program.
- Surveys designed to test the knowledge of students and teachers in fish pond production as well as the benefits of fish nutrition will be conducted before and after trainings given in the school pond system.
- Household consumption patterns will be determined for households participating in the study by evaluating the consumption of fish in each household befpore and after the project is done. These studies will use the methodology developed in Investigation 3.

Schedule

Establish ponds and women's groups. 1 October 2013 through December 2014. Final report will be completed no later than 30 August 2015.

TOPIC AREA

POLICY DEVELOPMENT

❖

POLICY RECOMMENDATIONS TO IMPROVE FOOD SECURITY AND HOUSEHOLD NUTRITION THROUGH SUSTAINABLE AQUACULTURE AND AQUATIC RESOURCE MANAGEMENT IN CAMBODIA AND VIETNAM

Policy Development/Activity/13PDV01UC

Collaborating Institutions and Lead Investigators

University of Connecticut-Avery Point (USA)	Dr. Robert Pomeroy Sylvain DeGuise
Inland Fisheries Research and Development Institute (IFReDI) (Cambodia)	Dr. Prum Somany Mr. Chheng Phen

Objective

The objective of this activity is to provide science-based policy recommendations to government and fisheries and aquaculture communities and households, including vulnerable subpopulations such as women and children on the potential risk of lacking food security and malnutrition due to the impacts of climate and non-climate drivers of change on fisheries and aquaculture and planned (policy-driven) adaptation strategies.

Significance

The productive Mekong fisheries are essential to the food security and nutrition of at least 60 million people of the Lower Mekong Basin (LMB). Fish, from capture and culture, are a significant source of income and food security in Cambodia and Vietnam. The combination of high fish biodiversity, high productivity, high exploitation rate, long-distance migrations, and fish trade make protecting these fisheries and aquaculture of great importance. However, they are highly vulnerable to climate and non-climate (specifically water development such as hydropower dam development) related drivers of change which will lead to flow change and ecological change in the Mekong basin, especially down stream countries like Cambodia and Vietnam. This includes increased temperatures; changes in rainfall patterns; changes in the hydrological regime (water levels, duration of flooding, timing of flooding); changes in run-off or sediment load/movement; and increased instances of extreme weather events (storms, floods and droughts). Saline water intrusion in the Mekong River was about 20km at the end of the 20^{th} century and is now up to 50km. These drivers of change will pose significant challenges for fisheries and aquaculture production, household income, livelihoods, markets and trade, gender issues, food security and the nutrition and health of people, especially poor households, in the LMB of Cambodia and Vietnam. However, a complete understanding of the impacts of each individual driver and a combination of drivers is only just beginning. The other five investigations of this project will provide science-based information on the impacts of climate and non-climate drivers of change on fish value chains, vulnerable populations, aquaculture production systems and capture fisheries. Adaptation is urgently needed to foster the resilience of the fisheries and aquaculture sectors in Cambodia and Vietnam. Adaptive strategies can take the form of processes, actions or outcomes in order to better adjust to, cope with and manage changing conditions (Smit and Wandel 2006). Adaptation mechanisms can be differentiated along several dimensions: by the purposefulness of adaptation (whether the adaptation is planned or unplanned), by the timing of implementation, by spatial and temporal scale, by sector of activity, or by which actors are designing and implementing the mechanisms (Adger et al.2007; Smit et al. 1999). Adaptation strategies for aquaculture and fisheries systems will be examined in several of the investigations of this project.

Quantified Anticipated Benefits

1. 100 scientists, researchers, resource managers, government officials, and non-government organizations in Cambodia and Vietnam will be better informed and have better information on current and potential impacts of climate and non-climate drivers of change on food security and nutrition and corresponding adaptation strategies.
2. 1,000 fisheries and aquaculture household s in Cambodia and Vietnam will be better informed and have better information on current and potential impacts of climate and non-climate drivers of change on food security and nutrition and corresponding adaptation strategies.
3. 200 women in fisheries and aquaculture households in Cambodia and Vietnam will be better informed and have better information on current and potential impacts of climate and non-climate drivers of change on food security and nutrition and corresponding adaptation strategies.
4. This investigation will provide return benefits to the US by allowing the Lead PI to expand his work in SE Asia on food security and fisheries and climate change and return this information and knowledge to graduate students in the University of Connecticut.

Research Design and Activity Plan

Location of work

The activity will be undertaken in the Lower Mekong Basin region of Cambodia and Vietnam.

Methods

Merely identifying a suite of potential adaptation options will not be sufficient to address these drivers of change. There is a need to provide this information to government and fisheries and aquaculture households and vulnerable populations to be able to make informed and deliberate decisions on adaptation. As an activity, the purpose is not to generate new information but to disseminate and communicate information generated by the studies in the project. Specifically, science-based policy recommendations. This investigation will provide this information through a suite of different communication methods and approaches for each audience.

Key activities will include

Activity 1. Audience analysis. The identification of target audiences (Scientists, researchers, resource managers, government officials, NGOs, fishers, aquaculturists, women) and their specific information requirements and methods of receiving information, and appropriate communication products (e.g. policy briefs, technical report, journal articles, web media) and the style of communication including scope, where and how to receive information, language, technical content. Focus Group Discussions (FGDs) will be conducted with rural farmers to identify appropriate communication channels for information dissemination and workshop with Scientists, researchers, resource managers, government officials, NGOs, fishers, aquaculturists, as well as women to analyze their preferences of communication channels.

Activity 2. Project products. The project documents and other team members will be reviewed to extract key messages to be presented in the communication products. Review policies and technical papers from other investigations to develop key communication messages for targeted audiences.

Activity 3. Communication and dissemination strategy. Communication strategy will be formulated and implemented by PI/communication expert. The communication strategy is a combination of approaches, techniques and messages to reach different audiences. Printed media such as Posters, leaflets and flyers will be printed for dissemination. Video spot on climate change and livelihoods will be produced and aired. At a minimum, the strategy will aim to effectively disseminate the following to key audiences:
5 technical reports:

1. Marketing, economic risk assessment and trade (MER) - impacts of climate and non-climate drivers of change on fish value chains.

2. Sustainable feed technology and nutrient input systems (SFT) - continuation of snakehead feed work.
3. Climate change adaptation: indigenous species development (IND) - sustainable snakehead aquaculture development in Cambodia
4. Watershed and integrated coastal zone management (WIZ) or mitigating negative environmental impacts (MNE) - carrying capacity work
5. Human nutrition and human health impacts of aquaculture (HHI) - impacts of climate and non-climate drivers of change on wild fish and aquaculture on vulnerable populations (women and children), fish availability, fish consumption

Schedule

The duration of implementation of this proposed investigation will be 24 months, starting from 1 October 2013 to 30 September 2015.

Year 1 (10/01/2013 – 09/30/2014):

- Audience analysis (participatory rural communication appraisal)
- Identify communication channels
- Develop Communication Message
- Set up Information and Dissemination strategy

Year 2 (10/01/14 – 09/30/2015)

- Review technical reports from other investigations for publication
- Message development and testing
- Preparation of publications for peer-reviewed journals; dissemination of information via workshops, fact sheets, etc.

Deliverables

- Three science-base policy briefs
- Printed media such as posters, leaflets and flyers
- Video spot on climate change and livelihoods will be produced and aired.

TOPIC AREA

MARKETING, ECONOMIC RISK ASSESSMENT, AND TRADE

❖

IMPROVING NUTRITIONAL STATUS AND LIVELIHOOD FOR MARGINALIZED WOMEN HOUSEHOLDS IN SOUTHWEST BANGLADESH THROUGH AQUACULTURE AND VALUE CHAIN ANALYSIS

Marketing, Economic Risk Assessment, and Trade/Study/13MER04NC

Collaborating Institutions and Lead Investigators

Department of Agricultural Management (Philippines)	Wilfred Jamandre
North Carolina State University (USA)	Upton Hatch
	Russell Borski
University of Dhaka (Bangladesh)	Abu Torab M. A. Rahim
Khulna University (Bangladesh)	Sattyananda Biswas
Southeast Asian Fisheries Development Center (Philippines)	Emilia Quinitio
Bangladesh Agricultural University (Bangladesh)	Md Abdul Wahab

Objectives

The focus of this investigation is to better identify the role aquaculture species play in the lives of impoverished women culturists in Southwest Bangladesh, with specific focus on the nutritional and economic benefits (both potential and actual benefits) derived from these endeavors. Through value-chain analysis, in concert with training on best management practices, we expect to generate improvements in household nutrition and economic profitability for the benefit of impoverished women in coastal Bangladesh. Specific objectives include:

1. Determine present status of household nutrition through surveys to understand the contribution of cultured fish species to the nutrition of women-led households.
2. Disseminate better management practices, including the integration of tilapia, to facilitate both greater availability of fish for household consumption, and environmental sustainability for the current farming practice of mud crab fattening/culture.
3. Study the value chain of tilapia and mud crab culture to firmly establish the role of women, within multiple segments of the value chain, to enhance their empowerment, incomes and livelihood.
4. Formulate policy recommendations to improve the nutritional status and livelihoods of marginalized women-led households in the Southwest region of Bangladesh through integrated and diversified aquaculture practices and an improved value chain.

Significance

Coastal (southwest) Bangladesh is highly vulnerable to the impacts of global climate change, and due to extreme poverty and malnutrition, is an important target area for the USAID "Feed the Future" Initiative. Within coastal Bangladesh, three districts (Satkhira, Khulna and Bagerhat) that surround the Sundarban mangrove forest are considered the most threatened, suffering repeatedly from the effects of calamitous storms (*e.g.*, cyclone Sidr, 2007; Aila, 2009). During periods of high flooding, the average consumption of staple rice falls to 33 % of their minimum nutritional requirement, resulting in acute malnutrition and chronic energy deficiency, particularly in women and children (World Food Programme, 2011). While men in this region commonly engage in day labor or have migrated to urban areas to obtain low-income work, the majority of women in this population rely directly on subsistence farming of natural wetland resources. The prevalence of impoverished women-led farming households in coastal Bangladesh, traditionally underrepresented in the economic market chain, make this demographic particularly susceptible to exploitation and thus a key target for improving dietary nutrition and earned incomes of the impoverished Southwest. As fish commonly contribute 63% of dietary animal protein intake for Bangladeshis (Belton *et al*., 2011), this investigation will focus on two key aquaculture species, tilapia (*Oreochromis spp.*) and the mud crab (*Scylla serrata*), the latter primarily cultured alone, but may be integrated with tilapia. We anticipate that integrative culture of these species can significantly improve the nutritional and economic well-being of female-led households as well as the environmental impact associated with crab-fattening where feed inputs are significant and water exchanges are common, leading to excessive inputs to the environment. A key component of this study will be to promote the culture of *both* species by women to foster better food security through diversification of dietary resources. A secondary benefit of this strategy is that tilapia can also be used as feeds for mud crab fattening, which are traditionally reliant on fisheries by-catch. The co-production of both species, combined with ongoing research into crab hatchery development (through activities at WorldFish; Dhaka, Bangladesh) will go a long way towards securing an environmentally sustainable industry and promote better food security for impoverished women aquaculturists in coastal Bangladesh.

The culturing or fattening of mud crab (*Scylla serrata*) is an emerging industry (Azam *et al.*, 1998; Khan *et al*., 1991) directly benefiting women-led households in coastal Bangladesh. The large-clawed mud crabs are high commodity seafood items due to their delicacy, medicinal value and demand in international markets (Ali *et al.*, 2004; Keenan *et al*.1997). Of the 2,428 crab farms in the severely impacted regions (Satkhira, Khulna and Bagerhat), 37.8% are currently owned and operated by women (26-41 % by region; Shushilan unpublished report). Even farms not directly owned by women commonly rely on this demographic for stock collection of juveniles from shrimp ponds or other wetlands. Currently, very little information has been collected or published about these endeavors, yet while women aqua-farmers likely obtain economic benefits from crab fattening, this is solely marketed as an export crop, thus may not directly benefit the dietary needs of women and children. Given a poorly defined value chain, where the roles and participation of women may be underestimated or under-appreciated by local government agencies, little protection from exploitation (by intermediary market buyers) currently exists. Through greater investigation of the mud crab value chain in the lives of women aquaculturists, this study will identify key opportunities and constraints for this industry, for which women play important roles.

To more directly improve the dietary nutrition of women and children, and create a sustainable method of mud crab fattening, our objective is to promote integration of seawater-tolerant tilapia (*Oreochromis mossambicus*) into traditional mud crab culture, thus providing greater crop diversification. The live mud crab industry holds promise for improving economic opportunities in regions sensitive to global climate change (e.g. seawater incursion, storms), with current annual production estimates at 10-15,000 mt (Zafar and Siddique 2000). Despite economic benefits, the dietary conditions for many women-led households in these regions are extremely poor, and may constitute only staple rice, supplemented periodically with local vegetables and fish (S. Biswas, pers. comm., 2013). As tilapia farming continues to grow in Bangladesh (Ahmed, 2007), including in the Southwest region (Hussein, 2009), the integration of tilapia into mud crab culture may enhance the incomes of women-led households through sales in domestic markets, and improve their food security by direct household consumption. The growing number of Bangladesh tilapia hatcheries and the availability of seed stock readily allow for integration of tilapia into traditional mud crab farming. As tilapia is commonly grown worldwide, its value chain nonetheless varies widely depending on local culture practices and market conditions. We will evaluate the tilapia value-chain in conjunction with that of mud crab to facilitate the development of both industries and their potential integration within the Southwest.

The farming of tilapia can also substantially improve the environmental footprint of mud crab farming. Recent investigations by the ProsCAB project (Anon, 2008) found that traditional fattening practices suffer from over-reliance on fisheries by-catch for crab feeds, and poor water quality in the holding ponds and receiving waters, which result in harmful algal growth. This study will address these problems by testing whether excess tilapia juveniles, reared in the crab ponds, can be used as feeds for the crabs, thus reducing the reliance on fisheries by-catch. Through extensive training of women farmers in the best management practices of tilapia-mud crab farming, we anticipate improvements in environmental water quality, through better knowledge and utilization of feed/fertilization inputs. As the tilapia will feed solely on pond primary productivity, otherwise harmful nutrients will be utilized by the system in our stratified design.

This study is designed to foster greater participation of women in aquaculture in the impoverished coastal regions of Bangladesh, achieved through a better understanding of their role in the economic value chain. Through integrative polyculture of tilapia with mud crab fattening, these investigations promote better food security and dietary nutrition for women-led households through greater crop diversification and training in best management practices for tilapia – mud crab culture. Currently, the production systems for mud crab fattening are less advanced relative to other aquaculture sectors (Begum *et al*., 2009). This investigation will provide on-site training along with current research into mud crab farming (*e.g.* captive breeding of seedstock, water quality, cage culture), to achieve sustainable development for this industry.

Quantified Anticipated Benefits

The completion of a nutritional and value chain analyses for tilapia and mud crab culture, examining the role and benefit derived by the women aquaculturists, will allow policy makers and NGOs to intervene in the production and value chain where necessary to directly improve household nutrition and earned income for impoverished women to better protect this demographic. More specifically, these anticipated benefits may include:

1. The ability of women involved in aquaculture to reap employment, nutrition and income benefits from aquaculture will increase.
2. Bangladeshi women producers in Southwest region will diversify their dietary nutrition and income opportunities through integrated tilapia-mud crab pond culture.
3. Improvements in market and processing activities will provide additional employment opportunities with expanded roles for women in these tasks.
4. Practical training and information regarding best management practices will improve existing practices for mud crab fattening in these regions as well as the new integrated tilapia-mud crab design (100 participants)
5. Greater adoption and inclusion by women in aquaculture will provide greater opportunities for mitigating the negative nutritional and economic effects of global climate change for coastal Bangladesh.

Plan of Work

Location

These studies will be conducted in the Khulna, Satkhira, and Bagerhat districts of Southwest Bangladesh, with on-site interviews conducted by W. Jamandre, U. Hatch, S. Biswas, S. Haque and A. Torab. The workshop and on-site extension training will be conducted by E. Quinitio, S. Biswas, and other local experts.

Methods

1. Determine the present status of household dietary nutrition through surveys to assess the contribution of seafoods, including mud crab and tilapia, in women-led households.

Household nutrition surveys will be conducted within the study area by Dr. A. Torab Rahim and S. Biswas. These surveys will focus on food consumption, and how low-intensity culture species (including mud crab and tilapia) and other seafoods contribute to the dietary nutrition and earned incomes (both actual and potential) of surveyed families. A baseline survey will first be conducted by pre-tested questionnaire before the intervention program (see Study 2), utilizing both qualitative and quantitative methods of data collection (Swindale and Belinsky, 2006). Household demographic and socio-economic information will be collected through collaborative participation with local NGO partners, government representatives, or other relevant stakeholders. The sample size for these surveys will be determined according to FANTA III sampling guide (Magnani, 1999; 2012 addendum). This value will be increased by 10% to account for potential non-responses (N = ~200 individuals). A second survey will be performed on a subset of those families that participated in the baseline survey and who undertook pilot studies on integrative tilapia-mud crab culture (Study 2A) to determine if income and tilapia consumption increased within the household. During the program, a subset of targeted households containing women aquaculturists will be followed, with each member of the household identified (average 4 per household, including children < 5 years of age, or females of adolescent age or younger) will be tracked. Statistical analysis, including household dietary diversity scores; will be performed using SPSS following the tabulation, classification, and coding of collected household data (Magnani, 1999; Swindale and Belinsky, 2006).

2. Disseminate better management practices for integrated tilapia mud crab culture to facilitate food security and economic well being of women-led households.
2A: Integrated tilapia-mud crab culture practices: This pilot study will demonstrate the potential benefits of integrated tilapia and mud crab culture to practicing women aquaculturists who utilize mud crab-fattening as a source of income. The benefits of integrating tilapia into mud crab fattening will be shown by the following: 1) greater supply of nutritious foods for household consumption, 2) improved earnings by the sale of extra tilapia in domestic markets, 3) improved environmental water quality resulting in less stock mortality and environmental impacts, and 4) a decrease in the reliance of fisheries by-catch for use as crab feeds. The latter benefit, utilized through feeding of extra juvenile tilapia to crabs, will also improve the environmental sustainability of this industry. The design is as follows:

Participating members from women-owned farms or from women-led households will be included within the sample set identified in Study 1 (N = 45 ponds, ~180 household members). Sites will be selected to have a salinity range (5-25 ppt) tolerant for tilapia (*O. mossambicus*) breeding and mud crab fattening (Popma and Masser, 1999; Shelly and Lovatelli, 2011). If possible, an equal number of ponds from all three districts (Kulna, Satkhira, and Bagerhat, 15 per district) will be used. Ponds will be randomly assigned to 1 of 3 treatment groups (N = 45; n = 15): (1) control – only traditional mud crab fattening practiced, (2) integrated tilapia-mud crab farming where the tilapia are sold to market, and (3) tilapia-mud crab farming where the tilapia are directly consumed by the household. In the tilapia groups, small juveniles (~10g, produced by tilapia breeding within the ponds) will be harvested weekly for use as supplemental crab feeds. Treatments 2 and 3 will be stocked with mixed-sex tilapia of breeding size (3 female: 1 male) at a density of 1 fish/m^2. The study will be conducted over a single tilapia production phase (2 crab fattening cycles). Mud crabs will be stocked at an equivalent, standardized density (2-3/m^2) for all ponds. The tilapia will be raised only on pond primary productivity derived from excess crab feeds, and fertilized (28 kg N, 7 kg P/ha) only if productivity is low (> 40 cm Secchi disk depth). Water quality will be monitored weekly by Secchi disk readings in all ponds, with further chemical analysis (total nitrates, phosphates, dissolved oxygen) tested at bi-weekly intervals for a subset of each treatment group (n = 3; N=1), which will be analyzed at the Water Quality and Pond Dynamics Laboratory at BAU. All participating households will be given a data collection notebook to record crab feedings, yields of tilapia (kg) harvested, proceeds from crab and tilapia sales (yield, kg; market returns), and input costs associated with crab feeding. Evaluation of nutritional benefits derived from direct consumption of tilapia will be examined as part of Study 1. Crop production (tilapia and mud crab) yields, estimated market returns, environmental water quality, and input costs between treatments will be evaluated by Analysis of Variance using SPSS.
Null hypothesis: There is no difference in total pond production yield, feed input costs, household nutrition, environmental water quality, or economic return when tilapia are integrated with the existing practice of mud crab fattening.

2B: On-site training workshop: In Bangladesh, aqua farmers have been practicing mud crab fattening mainly in earthen ponds; however, escape through burrowing is a common problem. High mortality and poor survival are the main production constraints. Introduction of cage culture and other innovative enclosures is new in Bangladesh though alternatives have been adopted in many Southeast Asian countries, e.g., bamboo (DA, Region VI, 1988) and net cages (Kuntiyo, 1992) in the Philippines, bamboo enclosure and cage in river and canals in Myanmar (Felix *et al.* 1995), and floating cage culture in Vietnam and Malaysia (Sivasubramain and Angel 1992). E. Quinitio (Co-PI) will evaluate current mud crab fattening and culture practices and conduct a training workshop on best management practices in the 2nd year of the project. The progress of Study 2A will be assessed and an additional on-site training workshop for women aquaculturists will be conducted in the 3rd project year. This workshop will be designed to help women aquaculturists improve their farm practices including potential integration of tilapia. An analysis of the best management practices for tilapia and mud-crab farming will be presented with suggestions for future improvements based on research gleaned from other Southeastern Asian countries with similar environmental conditions and culture practices. Site identification and logistical support for the training and on-site workshops will be undertaken by S. Biswas (Shushilan NGO), and focus on a diverse range of topics regarding current and future practices of the industry (e.g. culture systems, integrative aquaculture, and hatchery/nursery technologies, aqua-silviculture). Additional topics will include current shortages and high feed prices associated with reduced by-catch, the value of tilapia as a crab feed alternative, and the need for integrative polyculture to address nutritional needs for regions severely impacted by global climate change.

3. Value chain analysis for tilapia and mud crab to establish the role of women, in different segments of the value chain, to promote their empowerment, income and livelihood status.

A secondary data series for value chain analysis of tilapia and mud crab (Jamandre and Hatch) will be obtained from Bangladeshi government agencies, academic universities, WorldFish, and NGOs. Previous studies on production/marketing and women's role in aquaculture will also serve as a source of documenting information. The results of the nutritional survey along with data collected from Shushilan NGO (S. Biswas) will be used for targeting the value chain analysis as well as provide recommendations toward improving the socioeconomic and nutritional well being of disadvantaged women. The analysis will employ institutional economics concepts to identify and focus where governance, structure and efficiency can be improved for the benefit of impoverished coastal women. It requires evaluation of the value chain map (transaction costs, processes, power structures) and identification of intervention areas (Cooper et al. 1997). The following primary data will be collected: key players and their respective roles, activities, and services provided; supply chain product requirements (especially quality standards); information and money flows; critical logistics issues (including problems in production and marketing); extension services; and external influences (Williamson 1979). The existing production/marketing system imposes constraints on the opportunity for women fully benefiting from their participation in aquaculture (Ferdoushi and Xiang-Guo 2010). This analysis will focus on improved understanding of the local, regional and national supply/value chain (Ramasamy 2007) and the ability of local women producers to benefit from production for and marketing to consumers outside the local area. Value chain maps will be developed for each market level and performance will be evaluated for efficiency, flexibility and overall responsiveness. A similar methodology was employed in previous CRSP work for the Phillipines (tilapia farming; Jamandre and Hatch 2010). Relevant studies (Ferdoushi and Xiang-Guo, 2010; Zafar and Ahsan, 2006) will be used to provide essential background for understanding the role of women in aquaculture production and marketing systems and for further corrective recommendations.

4. Formulate policy recommendations to improve the nutritional status and economic livelihoods of marginalized women-led households

The nutritional and value-chain analysis will used to generate recommendations for improving the production practices and marketing systems of cultured species to greater assist impoverished women-led households. Current best management practices, with particular emphasis on the role of women in the economic value chain will form the basis for these recommendations, along with other research conducted under similar conditions in other countries of Southeast Asia. Improved value chain analysis and understanding will lead to greater ability for women culturists to participate in the local, national and international value chain. Specific policy recommendations will be formulated to target increased nutrition and well being of women through improved tilapia-crab integrated culture and value chain promotion.

Schedule

Oct 2013 - Mar 2014: Initial nutrition survey on seafood consumption (Study 1). Quinitio will evaluate current practices and conduct an initial training workshop (Study 2B) to provide an overview of better management practices. The collection of secondary data; interviews with government and academic experts as well as marketing sector participants will be done for value chain analyses.
March - Dec 2014: Tilapia-mud crab integrated aquaculture demonstrations (Study 2A), with assessments of household consumption and income (Study 1). Preliminary value chain analysis (Study 3) completed and identification of additional data and information needed for collection during follow-up in country travel.
Jan - Mar 2015: In-country travel for data collection and interviews as needed to complete value chain analysis. On-site training workshops conducted by E. Quinitio and other team members (Study 2B).
Mar - Sept 2015: Analyses and final report.

Deliverables

1. The contribution of seafoods or lack thereof to the diets of women (and their children) whose primary livelihood is aquaculture will be described with over 200 individuals surveyed.
2. The ability of women involved in aquaculture to reap the employment, nutrition and income benefits will increase through an understanding of the tilapia and mudcrab value chain (60 individuals interviewed).
3. The nutrition and economic benefits of 45 women-led households in 3 districts of the coastal Southwest will directly benefit through on-farm demonstration trials of integrated tilapia-mudcrab fattening culture. We anticipate significant improvements in fish consumption, earned income, water quality and reduced reliance of fisheries by-catch when tilapia farming is integrated with mud crab.
4. Two workshops, including on-site training will provide practical information to assist women in adopting improved culture practices (100 participants).
5. Two graduate students will obtain training on value-chain analyses, nutritional survey development and analyses, and on integrated tilapia-mud crab culture.
6. Documentation and Dissemination– The research outlined in this investigation will be reported through the Technical Reports of the AquaFish Innovation lab and in the theses work of participating students. We anticipate final publication of these results, if successful, within the peer-reviewed literature (1-2 papers).

SEAFOOD MARKET INFORMATION SYSTEM (SMIS) IN GHANA: APPLICATION TO TILAPIA

Marketing, Economic Risk Assessment, and Trade/Study/13MER01PU

Collaborating Institutions and Lead Investigators

Kwame Nkrumah University of Science and Technology (Ghana)	Stephen Amisah
Purdue University (USA)	Kwamena Quagrainie
FarmerLine (Ghana)	Alloysius Attah

Objectives

1. Develop an electronic system for tilapia market information exchange.
2. Develop a phone-based market information sharing platform for fish producers, fishermen, seafood marketers, and consumers.
3. Train fish farmers, fishermen, women fish processors, markets and traders on the use of the market information system developed under 1 and 2 to enhance trade and profitability.

Significance

An analysis of tilapia value chain in Ghana under a previous AquaFish CRSP project revealed challenges in the flow of information along the value chain, especially information relating to tilapia supply, demand and prices. For small-scale fish producers and artisanal fishermen, readily available market information on prices and demand for tilapia at different fish markets will help inform production and harvesting decisions. Minimizing the information gaps along the tilapia value chain will greatly improve efficiencies in tilapia marketing and the value chain as a whole. There is a need therefore to develop a marketing information system for tilapia in Ghana. A market information system involves processes to generate, store, analyze, and disseminate marketing information on a regular basis. A similar system is in use in Indonesia (InfoFish, 2010, 2008) and Kenya (KMFRI, 2010). In Indonesia, the Fish Marketing Information System provides a platform for a transparent and fair fish trading and improves market access for fish products from Banda Aceh to regional markets (InfoFish, 2010).

A seafood marketing information system (SMIS) in Ghana will be useful for efficient operation of the tilapia value chain. Opportunities for improved communication and increased information flow along the tilapia value chain exist in Ghana through the use of mobile phone technology. Mobile phone penetration in Ghana is 94%, making this an ideal channel linking fish producers and artisanal fishermen with markets. Mobile-based service opens these communication pathways and allows market data and information to be programed and can be easily accessed by users from a mobile device via voice and/or short messaging service (SMS) anytime. These services could result in increases in fish quality and yield as well as an increase in incomes of farmers and traders. An efficient market information system via the mobile technology has an important role to play in improving aquaculture productivity and value chain efficiency in Ghana. A marketing information system for tilapia in Ghana will results in a more organized tilapia market data collection, the storage of important tilapia market data, better coordinated marketing intelligence information, and access to market information to make business decisions. It will also assist in building capacity to improve the skill of stakeholders on fish marketing.

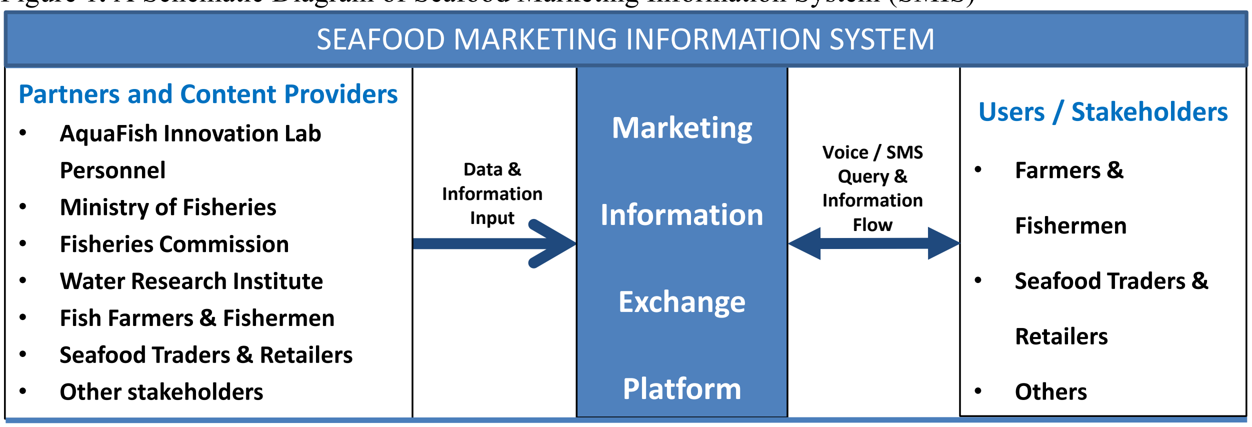
Methodology

The first step will involve identifying various points of tilapia fish supply and demand in Greater Accra, Eastern, and Ashanti regions in Ghana. A visit to selected supply and demand centers will help to identify important variables for which data and information will be collected, e.g., quantity, prices, trends, etc. The data will be collected from the various stakeholders including fish producers, artisanal fishermen, middlemen, fish marketers and retailers. Some key individuals or point persons will be identified at these locations to collect the data and information. The data will then be transmitted to a central database at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana and *Farmerline.*

The services of a programming company, *Farmerline* will be used to program an electronic information system into which the data and information collected from the supply and demand centers will be transmitted, creating a database/platform. The system will be set up in a form that can easily be accessed by users from a mobile device via voice and/or SMS anytime (Figure 1). This procedure involves detailed programming by *Farmerline* to build the electronic platform using the *Infolink* framework, which is a web based application (calls are sent from the internet). The technology behind *Infolink* web component is built with Laravel (PHP framework) and Twitter Bootstrap. The telephony component is built with *Plivo* in combination with *Freeswich*. There is GoIP (hardware containing GSM sim cards) attached to the server. The sim cards in the GoIP takes the command from the web application and makes the call like a normal phone call.

Targeted features of the system include the ability to query for particular kinds of information; communicate with large numbers of users; and messages received in native languages. Users will dial or text to a number and will receive messages through either voice or SMS on key market information in the database. Queries can be made for market information at particular locations. The SMIS will be web-based and will also provide fish market information on-line in addition to via voice/SMS to stakeholders.

Figure 1**.** A Schematic Diagram of Seafood Marketing Information System (SMIS)



Detailed statistics can be obtained on the number of users and how messages are received. The system will also include a tool that allows the conduct of immediate or longitudinal surveys with users. The survey tool will include recorded questions and users would answer by simply pressing buttons on their phone, and their responses are recorded immediately.
The new technology will be tested with fish farmers, fishermen and seafood traders. There will be two training programs on how to use mobile phones to relay/receive information on prices and other market data to/from the platform. Fish farmers and fishermen will be trained separately from the fish traders. The later training will target women seafood traders.

Deliverables

1. A database of tilapia quantities, prices and other market information
2. An electronic platform for tilapia market information sharing for producers, marketers, and consumers
3. Enhanced tilapia trade activities
4. The products will be available to stakeholders via their mobile phones. This presents ready access and use of the system developed.
5. Two training programs on how to use mobile phones to relay/receive information on prices and other market data to/from the platform will be offered to stakeholders.

6. Findings from the investigation will be presented at regional and international professional conferences.

Beneficiaries
Fish farmers, fishermen, fish processors, seafood traders and retailers, policy makers, academia, etc.

Quantifiable Anticipated Benefits
1. Detailed statistics on stakeholder use of SMIS.
2. One-stop shop for organized market data on tilapia. This will provide resources for the development of marketing plans and strategies as well as inform policy.
3. Access to sufficient market information and market intelligence that are needed for informed decisions.
4. Database assembled over a period of time will be available to US researchers for any quantitative analysis of the tilapia market in Ghana.

Future Plans
SMIS will become a pay-per-use system because of airtime minutes. Pricing arrangements will be made with mobile phone companies. Prices will take into account the cost of system maintenance, secured server services, audio recording in local languages and programming support. In the long-run, the system should be self-supporting.

Schedule

a) Identify points of fish supply and demand b) Identify selected variables for which data and information will be collected, e.g., quantity, prices, trends, etc c) Identify key individuals to transmit data and information to the database	July - December 2013
Programming the electronic information platform	January - July 2014
a) Data and information collection from the supply and demand points to a data center. b) Data and information programming into the system and set up in a form that can be easily accessed by users from a mobile device via voice and/or SMS anytime.	May 2014 – September 20115
Testing of the Seafood Market Information System (SMIS) and fine-tuning the platform	October – December 2014
Training fish farmers and artisanal fishermen in the use of SMIS	February 2015
Training women fish processors, markets and traders in the use of SMIS	March 2015
Launch and Reporting	April - September 2015

IMPACTS OF CLIMATE CHANGE ON FISH VALUE CHAINS IN THE LOWER MEKONG BASIN OF CAMBODIA AND VIETNAM

Marketing, Economic Risk Assessment, and Trade/Study/13MER03UC

Collaborating Institutions and Lead Investigators

University of Connecticut-Avery Point (USA)	Dr. Robert Pomeroy
Can Tho University (Vietnam)	Tran Ngoc Hai
Inland Fisheries Research and Development Institute (IFReDI) (Cambodia)	Hap Navy

Objective

This study will examine the vulnerability of the fish capture and culture sectors in the Lower Mekong Basin of Cambodia and Vietnam as it relates to the predicted impacts from climate change, using the concept of the value chain on fish markets and trade. The specific objectives of the study are (i) to identify current and potential impact pathways of climate change and corresponding adaptation strategies in selected fish value chains, and (ii) to provide evidence-based policy recommendations in order to contribute to sustainable development of aquaculture and fisheries in the Lower Mekong river basin.

Significance

The productive Mekong fisheries are essential to the food security and nutrition of the 60 million people of the Lower Mekong Basin (LMB). Fish, from capture and culture, are a significant source of income and food security in Cambodia and Vietnam. Freshwater fish consumption in Cambodia and Vietnam ranges up to 40 Kg/person/year, making them in the top three countries in the world. Fish contributes 81% of the population's protein intake in Cambodia and 70% in the case of Vietnam. Mekong inland fisheries provide employment to 1.6 of the 14 million Cambodians. In the Mekong Delta in Vietnam, 60% of the people are part-time fishers and 88% of the 'very poor' households depend on fisheries. Freshwater fish and fish products are traded throughout the LMB countries and internationally and markets for many products are well developed. Women play a very important role in fisheries sector, including capture and aquaculture. More than 80% of the fish traders and processors in the LMB are women. However, many capture fisheries resources have been largely overexploited and, as a result, development of aquaculture has been encouraged to provide the protein, income, employment and export earnings for Cambodia and Vietnam, especially for snakehead. The combination of high fish biodiversity, high productivity, high exploitation rate, long-distance migrations, and fish trade make protecting these fisheries and aquaculture of great importance. However, they are highly vulnerable to climate and non-climate (specifically water development such as hydropower dam development) related drivers of change. This includes increased temperatures; changes in rainfall patterns; changes in the hydrological regime (water levels, duration of flooding, timing of flooding); changes in run-off or sediment load/movement; and increased instances of extreme weather events (storms, floods and droughts) (Keskinen et al. 2010, Hoanh et al. 2010, Västilä et al. 2010, Lauri et al. 2012). Saline water intrusion in the Mekong River was about 20km at the end of the 20th century and is now up to 50km. These drivers of change will be felt throughout the fish value chain and will pose significant challenges for fisheries and aquaculture production; food security and the nutrition and health of people, especially poor households; household income; livelihoods; markets and trade; and gender issues in the LMB of Cambodia and Vietnam. However, a complete understanding of the impacts of each individual driver and a combination of drivers is only just beginning. Adaptation is urgently needed to foster the resilience of the fisheries and aquaculture sectors. Adaptive strategies can take the form of processes, actions or outcomes in order to better adjust to, cope with and manage changing conditions (Smit and Wandel 2006). Adaptation mechanisms can be differentiated along several dimensions: by the purposefulness of adaptation (whether the adaptation is planned or unplanned), by the timing of implementation, by spatial and temporal scale, by sector of activity, or by which actors are designing and implementing the mechanisms (Adger et al.2007; Smit et al. 1999). However, merely identifying a suite of potential adaptation options will not be a sufficient basis for decision-making. Better estimates of the benefits and costs of adaptation interventions are needed to guide design and prioritization at the policy level (Heltberg et al. 2009). This study will focus on autonomous adaptation at the farm level and draws implications for planned adaptation to address farm-level issues. While households have already responded to localized manifestations of climate change, governments can play a role in enhancing the adaptive capacity of fishers and farmers.

Quantified Anticipated Benefits

1. 200 scientists, researchers, resource managers, government officials, and non-government organizations in Cambodia and Vietnam will be better informed and have better information on current and potential impact pathways of climate and non-climate drivers of change and corresponding adaptation strategies for selected fish value chains in Cambodia and Vietnam.
2. Ten researchers in Cambodia and Vietnam will be trained and have experience on using value chain analysis to analyze sector-specific impacts of climate and non-climate impact pathways on fish value chains.
3. This study will support research activities of 1 PhD student, theses of 2 master students, and dissertations of 4 undergraduate students.
4. Number of women in fisheries and aquaculture households in Cambodia and Vietnam will be better informed and information on current and potential impacts of climate change on value chain of fisheries and aquaculture products.
5. The return benefit to the US from this project will be development of methods and results on understanding of the impacts of climate change on aquaculture and fisheries value chains. These methods and results should be applicable to US aquaculture and fisheries.

Research Design and Activity Plan

Location of work

The study will be undertaken in four provinces of Cambodia (Kandal, Kampong Chnang, Kampong Thom, and Siem Reap) and Phnom Penh and two provinces in Vietnam (An Giang and Tra Vinh).

Methods

This study will examine value chains for snakehead (capture in Cambodia and culture in Vietnam) and small-sized fish. The small-sized fish is considered “trash fish” caught by fishermen and sell to fish farmers for feeding cultured fish, such as snakehead fish. The study will build on previous research undertaken under the AquaFish CRSP in the Lower Mekong Basin of Cambodia and Vietnam that focused on snakehead and small-sized fish value chain analyses to provide a more in-depth understanding of issues facing the fish industry.

The value chain approach is a useful tool to study specific challenges facing a sector resulting from various drivers of change. Critically, such analyses can reveal context- and sector-specific adaptation strategies to enhance a sector. A value chain is defined as “the full range of activities which are required to bring a product or service from conception, through the different phases of production, delivery to final consumers, and final disposal after use” (Kaplinsky and Morris 2001). A value chain approach can be used to examine both micro and macro aspects, including the complex networks of production and trade comprising the fisheries and aquaculture sector. The value chain perspective is important because it offers insights that would not surface in studies focused on individual economic agents or particular policy frameworks. A value chain analysis can also uncover insights into the challenges that face the sector as a result of different drivers of change, such as climate change, including small firms’ and fishers’ competitiveness in changing markets. A value chain perspective can reveal response strategies that enhance the sustainability and competitiveness of the entire value chain and the economic agents that comprise it. Value chain analysis helps to effectively isolate the binding constraints that affect the sector in a systematic manner. The set of issues that emerge from such a detailed analysis at a sector level has implications for both the public and private sectors alike. Some of the issues are sector-specific, and others are relevant across an economy and apply to many sectors and firms in a country. It also provides an opportunity to find policy positions that can be supported by the sectors different economic agents and important stakeholders. At the heart of the analysis is the mapping of sectors and key linkages. The value chain analysis will consist of the following: First, at its most basic level, the value-chain analysis will systematically map the economic agents participating in the production, distribution, marketing, and sales of the particular fish product. Second, the value-chain analysis will identify the distribution of benefits of economic agents in the chain. That is, through the analysis of margins and profits within the chain, determine who benefits from participation in the chain and which economic agents could benefit from increased support or organization. Third, the analysis is used to examine the role of upgrading within the chain. Upgrading can involve improvements in quality and product design that enable producers to gain higher-value or through diversification in the product lines served. An analysis of the upgrading process includes an assessment of the profitability of actors within the chain as well as information on constraints that are currently present. Finally, value-chain analysis can highlight the role of governance in the value-chain. Governance in a value-chain refers the structure of relationships and coordination mechanisms that exist between economic agents in the value-chain. Governance is important from a policy perspective by identifying the institutional arrangements that may need to be targeted to improve capabilities in the value-chain, remedy distributional distortions, and increase value-added in the sector.

The value chain analyses conducted for snakehead and small-size fish through the previous AquaFish CRSP project will serve as the foundation for this analysis. The previous study described the value chains of captured and cultured snakeheads in the Lower Mekong Basin (LMB). The important actors involved in the value chain of snakeheads in the LMB of Cambodia and Vietnam were fishers, fish farmers, wholesalers, retailers, and processors. Two supportive groups also involved in these chains were market managers and sector officers. The value chain of wild captured snakeheads in Cambodia was focused on eleven marketing channels, of which the most important ones were: (1) “Fishers -> Wholesalers -> Retailers -> Consumers”; and (2) “Fishers -> Wholesalers -> Wholesalers in Phnom Penh city”. The distribution of benefits among the chain actors in Cambodia was unequal, with the highest proportion of profit going to wholesalers. The two most important channels among ten marketing channels of cultured snakeheads in the Mekong Delta region of Vietnam were: (1) "Farmers -> Collectors -> Retailers -> Consumers in the Mekong Delta"; and (2) "Farmers -> Collectors -> Wholesalers in Ho Chi Minh city”. Both benefits and costs were also distributed unequal between the chain actors while the highest profit taken by collectors. The description of the marketing channels will allow the new investigation to immediately focus on identifying current and potential pathways of climate change and corresponding adaptation strategies in the study areas.

The geographic area of focus is four provinces in Cambodia surrounding the Tonle Sap Lake and two provinces in Vietnam, one on the Mekong River near the Cambodian border and the other on the Mekong River on the coast. The two selected provinces in Vietnam will allow for climate change impacts to be assessed in both a riverine and coastal environment. This study will incorporate information from a review of current literature (secondary data) on fish value chains and climate change adaptation in Cambodia and Vietnam, supplemented with data from key informant interviews. The goal of the research is to obtain information on climate change exposure, sensitivity, and adaptive capacity of activities along the major fish value chains, and also to substantiate information gathered in the literature review. The information used will be drawn from literature assembled through an Internet search (such as the WorldFish Center Library) together with recommendations from key researchers in fisheries and aquaculture, both in Cambodia and Vietnam, and internationally. It includes relevant data on the status and trends within fisheries and aquaculture and their associated institutions, and on changes in climate. Semi-structured interviews will be conducted with various stakeholders in fisheries and fish farming. Interviewees will be those employed in the public and private sector, development institutions, and NGOs. The content of the interview questionnaire will be focused on the objectives of the study but limited by the time frame available. Qualitative data describing value chains of wild and farmed snakehead fish, as well as climate change, variability and adaptation will be collected. More specifically, climate change issues and its effects on aquaculture generally and snake head fish culture and capture particularly. Production and value chain issues on aquaculture generally and snake head fish culture and capture particularly. Plans, solutions and adaptation methods for the identified climate change issues and impacts on fish value chains. Participatory Rural Appraisal (PRA) meetings in each province, at least three meetings (10-30 persons/meeting) will be organized for groups of actors in the value chain (fishermen, farmers, traders, processors, and officials). Participants will be asked for information about the development of the current practices of capture and culture, market channels, and climate change issues, effects and adaptation methods. Data will be analyzed with descriptive methods, ANOVA using Duncan methods, and regression analysis utilizing Excel and SPSS programs.

To identify the impacts of climate change, we will use a combination of qualitative and quantitative information to assess potential bio-physical impacts of climate change on the selected fish species. Reviews of the literature and secondary data, combined with observation and consultations with local experts and stakeholders, will provide information to determine exposure and sensitivity impacts and trends from water temperature increases and changes in water supply and flow, the principal expected impacts of climate change on fisheries and ecosystems in the Lower Mekong basin region (Keskinen et al. 2010, Hoanh et al. 2010, Västilä et al. 2010, Lauri et al. 2012). The study will be structured using the vulnerability assessment framework of Allison et al. (2009) to understand the vulnerability of fish value chains to the key drivers of climate change. Vulnerability is defined as "a combination of the extrinsic exposure of groups or individuals or ecological systems to a hazard, such as climate change, their intrinsic sensitivity to the hazard, and their lack of capacity to modify exposure to, absorb, and recover from losses stemming from the hazard, and to exploit new opportunities that arise in the process of adaptation" (Allison et al. 2009). The key drivers of vulnerability in this system will be water temperature increases and changes in water supply and flow region (Keskinen et al. 2010, Hoanh et al. 2010, Västilä et al. 2010, Lauri et al. 2012). In order to understand the vulnerability of this system, the impact pathways and adaptation strategies to climate change will be evaluated for the major groups of actors at each level of the fish value chain for the selected species. This study will present context- and sector-specific adaptation strategies for products in the fish value chain contributing to domestic food security, nutrition, gender responsive and implementation, livelihoods, markets and trade, and national economic development. Effective adaptation must address climate change. Examples of adaptation strategies through the value chain include the application of KAP (knowledge, attitude and practice), development of the small-scale farming of snakeheads for women during the flooding season through an improvement of feed for a reduction of deformities and diseases of cultured snakeheads and improving the processing activities for an increase of added value of cultured snakehead products.

Schedule

The starting date is 1 October 2013. The completion date is 31 August 2015. Detailed activities plan:

Activities	2013	2014				2015			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
First meeting of the project members	X								
Preparing project introduction deliverables	X								
Preparing checklist, meeting local officials, collecting secondary information		X							
Prepared questionnaires, checklists, pre-survey, and finalize questionnaires and checklists		X							
PRA survey			X						

RRA survey to different stakeholders			X	X	X	X			
Local meetings		X				X			
International meetings					X			X	
Data analysis and writing report						X	X	X	
Preparing deliverables of project findings							X		
Training courses							X		
Participating international conference						X	X		
Project report submitting								X	

Deliverables

Deliverables of the project activities include:

- National and international workshops: one workshop will be organized in Cambodia and Vietnam each year.
- International conferences: project members will attend and present scientific papers each year during the project period.
- Posters, leaflets, factsheets: Information about the project and findings of the project will be prepared, printed and delivered popularly in posters, leaflets, and factsheets in local language.
- Websites: The project will utilize IFREDI, Can Tho University and University of Connecticut websites to exchange information.
- Papers: at least two papers are published on international journals and two papers are published in Vietnamese and Cambodian journals over the project period
- Monograph: one monograph on the issues of climate change and snakehead aquaculture; and one on issues of climate change and snake head fish fishing will be printed and published.
- Training courses: two training courses will be organized at different content, level, and places in each study country.

VALUE CHAIN ANALYSIS OF FARMED NILE TILAPIA (*OREOCHROMIS NILOTICUS*) AND AFRICAN CATFISH (*CLARIAS GARIEPINUS*) IN TANZANIA

Marketing, Economic Risk Assessment, and Trade/Study/13MER02PU

Collaborating Institutions and Lead Investigators

Purdue University (USA)	Kwamena Quagrainie
Sokoine University of Agriculture (Tanzania)	Sebastian W. Chenyambuga
	Nazael Madalla
	Elibariki Emmanuel Msuya

Objectives

The overall goal of this study is to characterize and identify areas of improvement in value chain of Nile tilapia and African catfish in Tanzania. Specific objectives are:

1. To identify and map various actors currently involved in Nile Tilapia and African catfish value chain and their functions;
2. To analyze marketing margins of the different sub-sectors of Nile Tilapia and African catfish value-chain as the produces move from producers downstream the value chain;
3. To identify the key constraints and problems affecting different actors in the value-chain;

Significance of the Study

In Tanzania Fish farming is currently being emphasized as an alternative to capture fisheries due to decline in wild stock from natural water bodies. The emphasis of the national fisheries policy (URT, 1997) is on a semi-intensive integrated mode of fish culture, focusing on Nile tilapia. The Nile tilapia is given first priority due to its better characteristics that include fast growth, short food chain, efficient conversion of food, high fecundity (which provides opportunity for distribution of fingerlings from farmer to farmer), tolerance to a wide range of environmental conditions, and good product quality (Hussain *et al*., 2000; Neves *et al*., 2008). Another species that is given priority is the African catfish (*Clarias gariepinus*). The African catfish is either cultured on pure stand or in polyculture with Nile tilapia. In the polyculture system the African catfish is used as a predatory fish species that eats the surplus fry, hence, controls undesirable tilapia recruitment in ponds and permits better growth of the adult Tilapia population. Small-scale aquaculture is an integral agricultural component of a broader farming system and is being emphasized as a one of the strategies for reducing risk in the farming communities. At the moment aquaculture is dominated by freshwater fish farming in which small-scale farmers practice both extensive and semi-intensive fish farming. It is estimated that the fisheries sector contribute 1.6% of the national GDP and about 27% of the animal protein consumed in the country. Unfortunately, the country statistics do not distinguish between aquaculture and wild capture as the source of fish. It is therefore, difficult to draw firm conclusions about the proportion of total fish consumed or traded from aquaculture.

Value chain analysis is the key entry point to poverty alleviation and achieving pro-poor outcomes. It is usually aimed at increasing the total amount and value of products that the poor can sell in the value chain (Hempel, 2010). This, in turn, results in higher absolute incomes for the poor as well as for the other actors in the value chain. The other objective of value chain analysis is to sustain the share of the poor in the sector or increase the margins per product, so that the poor do not only gain more absolute income but also relative income compared to the other actors in the value chain (Berg *et al*, 2008). Furthermore, value chain is used as an analytical tool for understanding the policy environment which enable efficient allocation of resources within the domestic economy to maximize value, prevent post-harvest losses, and ensure effective management is in place to promote sustainable utilization of the resources. Value chain analysis is done by mapping the actors participating in the production, distribution, marketing and sales of particular product (or products). The mapping involves assessment of the characteristics of actors, profits and costs structures, flow of goods throughout the chain, employment characteristics and the destination and volumes of domestic and foreign sales, identifying the distribution of benefits of actors in the chain, the role of upgrading and governance within the chain. In Tanzania little is known about the value chain of cultured Nile Tilapia and African catfish due to fact that no thorough study has been conducted on the subject matter, thus making the government put little effort to promote fish farming for poverty alleviation.

This study will employ value chain analysis (VCA) methodology. This is a holistic approach which, unlike conversional methods, assesses all key actors and their functions in the subsector from input supply, production, and postharvest to marketing. The study will involve collection of relevant data from all key players involved in generation and flow of product from the producers to ultimate destination and flow of value in the opposite direction. This will provide information that will help to identify policy issues that may be hindering or enhancing the functioning of the chain and also the areas that need improvement in the chain. In this way aquaculture production can be improved and contribute to poverty alleviation and food security effectively.

The proposed study intends to determine market channels of farmed fish and constraints facing fish farming in rural areas. In addition, the study will examine the contribution of small-scale aquaculture enterprises to income and food security of households in rural areas. This information will help in developing appropriate improvement programmes aiming at improving the productivity of fish farming in rural areas. This study will provide baseline information on the importance of aquaculture to small-scale farmers and the country's economy and will form the basis for formulation of aquaculture development project and policy. Moreover, the findings from the proposed study are important to the stakeholders and farmers for making proper decision with regards to investment in various sub-sectors of aquaculture.

Quantified Anticipated Benefits

The beneficiaries of this study will be various stakeholders involved in aquaculture, including fish farmers, processors, traders, consumers and policy makers. The expected outputs are as follows:-

1. Main actors and their functions and areas of improvement in the Nile tilapia and African catfish identified
2. Information on profitability of the different segments in the value chain of Nile tilapia and African catfish made available
3. Constraints and opportunities for the different segments in the value chain of Nile tilapia and African catfish identified
4. Solutions to overcome the barriers currently facing the various actors and to sustain and improve market participation by small-scale fish farmers proposed.
5. Women's and men's roles as well as differences in the constraints and opportunities for women and men identified and strategies to increase women participation in the different segments in the value chain of Nile tilapia and African catfish proposed.
6. Six fish farmers association formed and registered at district level.

Research Design or Activity Plan

The study will use purposive sampling to select six districts in the country where Nile tilapia and African catfish farming is practiced. Four villages per district will be randomly selected from the list of villages in which fish farming is practiced. The population for the research will be small-scale tilapia and catfish farmers, processors, traders and consumers in the selected villages. In each village a list of households involved in fish farming will be obtained from the village government and village extension officers. Ten small-scale fish farmers, five fish processors, five fish traders and 10 fish consumers per village will be randomly selected to participate in the study. Hence, the total sample size will be 240 fish farmers, 120 processors, 120 traders and 240 consumers. This study will be conducted in three (out of seven) agro-ecological zones (i.e. southern highlands, northern highlands and coastal zones) in Tanzania. In each zone two districts in which fish farming is predominantly practiced will be purposely selected. In each district four villages will be selected based on the intensity of aquaculture activities. Hence, the study will be conducted in 24 villages located in three agro-ecological zones of the country.

Methodology

Value chain analysis of farmed Nile Tilapia and African catfish

A value chain analysis (VCA) will be carried out to identify all actors involved in the chain of farmed Nile tilapia and African catfish, the linkages between them, and the activities within each link. Focus group discussions with key informants (i.e. fish farmers, extension officers, traders, retailers and restaurant owners) will be performed to collect information on key players in the value chain of Nile tilapia and their roles, how do tilapia and catfish products, information and money flow through the supply chain, type of activities and services carried out at each level in the supply chain and the factors that influence the performance in the value chain. Information will also be collected on market demand, buyer requirements, quality standards, and local, regional and national governance structures influencing the actors in the value chain. A household survey will be carried out to collect information on household characteristics and main economic activities. Apart from socio-economic characteristics information to be collected from fish farmers will include fish farming practices, species cultured, quantity produced, available markets and price and institutional supports offered to fish farmers. Information from processors will include source of fish, means of fish handling and processing, added values due to processing, transport and transportation facilities to markets and costs and revenues for their products and problems encountered. Traders are expected to give information on source and type of fish sold, trading facilities and information, available markets and costs and revenues of their products. Consumers will be asked to provide information on their species and product preferences and product standards required. In addition to value chain analysis, the study will assess differences in women's and men's roles along the value chain.

Analyzing marketing margins of the different sub-sectors of Nile Tilapia and African catfish value-chain

A household survey will be carried out to collected marketing financial data from each of the key value chain actors i.e. producers, processors and retailers). The profit for each stakeholder will be calculated using the following formula:

Marketing Margin (MM) = Sales Price (SP) - Purchase Price (PP)

Marketing Profit (MP) = Marketing Margin (MM) - Marketing Cost (MC).

For the fish farmers, marketing costs are the production costs which include costs of feeds, fertilizers, veterinary drugs, labor (family/hired), repair and maintenance of ponds. For the processors marketing costs are the transportation, primary processing and packaging costs. For traders the marketing costs are the transportation and all secondary processing and packaging costs. For the retailers who sell to end consumers the marketing costs are the transportation and advertisement costs and costs related to retail space/room utilization.

Identification of key constraints and problems affecting different actors in the value-chain

A cross-sectional household survey for the selected fish farmers, processors, traders and retailers will be conducted in the selected villages. Individual interviews with the different actors in the value chain will be conducted using a well-structured questionnaire with both close- and open-ended questions. Information will be collected on problems facing fish farming, processing, distribution and marketing of Nile tilapia and African catfish. In addition, barriers to entry into markets as well as opportunities and areas of improvement in the value chain will be identified.

Deliverables

- Outputs will include reports and peer-reviewed publications that will be made available to policy makers. These will be available online and in print.
- Findings from the investigation will be presented at regional and international professional conferences.

Schedule

Activities	2013/2014				2014/2015			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Objective 1:								
Activity 1.1: Development and pre-testing of questionnaire for household survey and checklist for focus group discussion	■							
Activity 1.2: Data collection through a household survey	■	■						
Activity 1.3: Data collection through focus group discussion			■					
Activity 1.4: Data analysis and report writing				■				
Objective 2:								
Activity 2.1: Development and pre-testing of questionnaire				■				
Activity 2.2: Data collection through a household survey					■	■		
Activity 2.3: Data analysis and report writing							■	
Objective 3:								
Activity 3.1: Development and pre-testing of questionnaire	■							
Activity 3.2: Data collection through a household survey		■	■					
Activity 3.3: Data analysis and report writing				■				
Final Report Writing								■

HOUSEHOLD FISH PONDS IN NEPAL: THEIR IMPACT ON FISH CONSUMPTION AND HEALTH OF WOMEN AND CHILDREN; AND THEIR CONSTRAINTS DETERMINED BY VALUE CHAIN ANALYSIS

Marketing, Economic Risk Assessment, and Trade/Study/13MER06UM

Collaborating Institutions and Lead Investigators

University of Michigan (USA)	James S. Diana
Agriculture and Forestry University (Nepal)	Madhav Shreshtha
	Narayan P. Pandit
	Ram B. Mandal

Objectives

1. To conduct an analysis of household pond production, harvesting, processing, distribution, markets, and sales in Southern Nepal;
2. To organize data into a value chain diagram and to use the diagram to draw insight on possible improvements in the aquaculture sector.
3. To determine the frequency and amounts of fish eaten by children ages 1-5, as well as women, from households with or without fish ponds;
4. To evaluate the health characteristics of children from households with or without fish ponds;

Significance

The government of Nepal has recognized that chronic malnutrition is a major problem in the country. The most common forms of malnutrition include undernutrition (insufficient energy) and deficiencies of vitamins and minerals, including vitamin A, iodine, and iron. About 41% of children less than five years of age are stunted (UNICEF, 2012a) and 48% are anemic (MoHP, 2006). Also, 36% of women, aged 15-49 are anemic (MoHP, 2006). Realizing this, the GoN signed the Declaration of Commitment for Accelerated Improvement in Maternal and Child Nutrition and launched the Multi-Sectoral Nutrition Plan (MSNP) on 17 September 2012 (UNICEF, 2012b). Much of our research and outreach in Nepal has focused on providing fish culture alternatives to improve the nutrition and health of poor farmers, but we have not yet done much to assess the success of increased fish production on human health.

Fish has been recognized as a nutritionally beneficial food source around the world. It has long been known that fish provide high quality protein and important micronutrients, such as vitamin A, vitamin D, and iodine, and they can also be a source of phosphorus, fluoride, and calcium if bones are consumed (Speedy, 2003). Additionally, the benefits of consuming fish for Omega-3 fatty acids has recently been widely documented (Oken and Belfort, 2010; Mahaffey et al., 2011). While certain fishes can provide all of these health benefits, there currently exists a difference in the perceived nutritional gains in developed versus developing countries: in the former, individuals, the media, and researchers are primarily concerned with Omega-3 fatty acids (Domingo et al., 2007; Oken and Belfort, 2010), while in the latter, the primary concerns are protein and micronutrients (Aiga et al., 2009; Parajuli et al., 2012). In Nepal, the benefits of fish consumption have been linked with such outcomes as improving protein intake (Bhujel et al., 2008) and increasing vitamin A and zinc ingestion (Parajuli et al., 2012). Little data exist in relation to fish production in Nepal, but approximately half of all fish produced in 1994/1995 was done so through aquaculture (FAO, 2012). It is believed that the majority of fish currently consumed in Nepal is produced through aquaculture practices since nearly all fish sold in markets in Kathmandu and surrounding areas are raised in ponds.

During summer 2012, we conducted our first study on the influence of household ponds on the health and nutrition of children in the household (Stepan, 2013). This study focused on small household ponds in Kathar and Kawasowoti, with a control population in Bhandara. The concept of small household ponds was originally extended to local residents to improve the nutrition of poor families in Nepal. These ponds have been deemed so successful by local residents that the number of ponds has increased from around 100 in the early stages to over 1,000, with the additional ponds built by local owner groups. All of the adopting communities are in the Terai region and are comprised mainly of Tharu people. The earlier study showed that children from homes with household ponds consumed about five times more fish than children in households without ponds. While it was clear that fish consumption did increase dramatically in households with ponds, it was less clear that this consumption resulted in increases in the height at age or weight at age for children from those households, or in the health of mothers or pregnant women. This was due in part to problems with the timing and intensity of our sampling; in addition, it was affected by the similar socioeconomic status of all participants. However, the survey did help detect some consistent patterns and also helped us to design better surveys for the future. One purpose of this study is to conduct such an expanded survey.

One issue related to the expected health improvements from people eating fish would be what other sources of protein are available to them. Most Nepalese families eat a largely vegetarian diet, focused on rice and some vegetables, with fish or meat added when available (Stepan, 2013). The Terai region of Nepal is its main agricultural area, with much production of rice as well as some livestock. Health improvements might not be measureable if households without ponds eat meat instead of fish. Our earlier survey had some flaws, mostly in the timing of sampling (in summer, eight months since the last fish harvest) as well as in finding sufficient families with young children (under the age of five) whose growth trajectories would be reflected by recent consumption history. In this study we intend to improve on these limitations by also measuring the amount of meat consumption, and by sampling more families so we can have adequate numbers of children under five.

Although aquaculture has been practiced in Asia for thousands of years (FAO, 2012), it is fairly new in Nepal. It was not until the 1940s that the country began raising fish, and an additional 40 years passed before any significant progress was made in the field (FAO, 2012). Considering Nepal's late start in aquaculture practices, it is no surprise that the county is yet to contribute substantially to the huge volume of Asian aquaculture production (Asia produced 92.5% of the world's total aquaculture in 2008) or benefit largely from the economic improvements that aquaculture has been shown to create (NACA, 2010). Recently, however, Nepal has shown marked increase in carp polyculture (FAO, 2012). We have completed a value chain analysis (VCA) of this system (Stepan et al., 2013), so for our next evaluation we will study household ponds as the target. While these ponds function mainly for family consumption rather than sales, the end use of the fish produced, as well as the methods for fingerling acquisition and other transfers of fish, have not been studied. Because these ponds are so popular, the second purpose of this proposal is to conduct a VCA on this system of aquaculture. Household ponds are very small scale, use indigenous species and local inputs for fertilizer and fodder. They also do not exchange water with the local area, so they represent an environmentally friendly form of aquaculture to be extended.

The general concept of a value chain is to link all steps of production, processing, and distribution of a product together, and then to analyze each step as it relates to those that precede and follow it. In doing so, the value chain describes all of the activities responsible for bringing a product from creation to ultimate disposal (Hempel, 2010). Given the early stages of aquaculture development in Nepal, a value chain would be best applied to evaluating limitations in the potential growth of the sector. Taking this into consideration, the following topics have been highlighted as research areas:

- Fingerling production – Is there adequate fingerling production to accommodate the demand for cultured fishes in Nepal? Are fingerlings wild caught?
- Seasonality – Rural lowland communities in Nepal are able to raise fish only in the monsoon season when water is plentiful. How does this restraint affect fish production?
- Transportation – How far away can fish be safely transported?
- Market concerns – What is the nature of the demand for cultured fish in Nepal?

Women play an integral role in the aquaculture and fisheries sectors all over the world. Even though women's roles and responsibilities are changing in some countries, there are constraints that limit female participation in aquaculture (Egna et. al., 2012). A few such constraints that women face in aquaculture and fisheries are: time availability and allocation, land ownership, and access to water, credit, training, and labor. Lack of training opportunities can trap women in vulnerable and poorly paid positions with no prospects of getting ahead (FAO, 1998). However, the situation in Nepal with household ponds differs considerably from this norm. In most of the poorer Nepalese households, women tend and manage gardens and ponds, while men seek work at outside locations (Bhujel et al., 2008). Therefore, household ponds enhance the income, nutrition, and status of women, and provide them with alternatives for their families.

This study is intended to focus on the value of household ponds in two ways: 1) to compare fish consumption and indicators of health for children and women in households with fishponds to those without access to ponds; and 2) to complete a value chain analysis of household ponds. To expand the reach of this study, we have initiated collaboration with Winrock International and the Nutrition Innovation Lab, two other NGOs concerned with human nutrition in Nepal. We anticipate that they will at least aid us in designing survey tools to complete this work, and we hope they will conduct similar surveys and outreach in other regions or for other types of consumers to gain an even larger database on consumption and nutrition in Nepal. We have initiated contact with William Collis (Winrock) and Patrick Webb (Nutrition Innovation Lab) about collaborating on this project and intend to develop these ideas further before initiating the study.

Quantified Anticipated Benefits

This study will provide a robust database on the nutrition of children in rural Nepal families and the role of fish consumption in their health. We intend to survey at least 200 families and, as a result, we anticipate that all of these families will gain a better understanding of nutrition and the role of protein in the health of their children. The results of this survey will also inform aquaculture extension in the country, as it will indicate whether ownership of small household ponds is truly aiding in the nutrition of these families.

The completion of a VCA for household ponds will provide better understanding of their strengths and weaknesses. Through this understanding, all of those involved in the sector, from fingerling producers to fish farmers to those possibly involved with fish sales, will be informed of management strategies to improve their service. This will lead to increased supply of high-quality fish protein to communities with limited food resources, and the overall growth of the aquaculture sector. We will document the increase in food supply through our survey of 200+ families.

Deliverables

Documentation of enhanced household fish consumption through pond aquaculture by survey and development of a fact sheet for further extension. Understanding of value chain for household ponds through a report and survey.

Research Design

Location

Since most aquaculture is done in the Terai region, we will focus our surveys there. We will use the advice of Winrock and Nutrition Innovation Lab colleagues, as well as faculty at AFU, to determine the best locations to focus these surveys. We do intend to survey at four different parts of the Terai.

Methods

- Social science survey of nutrition and value chain.

We intend to survey 50 households in each of the four locations selected.

- Our household surveys will evaluate the production details (source of fry, end use of fish) for household pond owners as part of the VCA.
- Once we have identified likely sources or markets for fish produced in household ponds, we will survey those participants as well to complete the value chain details.
- Social science survey instruments will be designed to determine the frequency and amounts of fish and meat eaten by children ages 2-5 as well as by women in the household. Special attention will be paid to the consumption of SIS, in addition to total fish consumption.
- We will monitor the height and weight of children from households surveyed, when possible, and compare these statistics among households with or without ponds as well as with national data.
- Value Chain Mapping will be done with data collected on uses and sources.
- Analysis of opportunities and constraints: Following the previous steps, opportunities for improvement and specific constraints of the household pond value chain will be described in a final report.

Statistical design, null hypothesis, statistical analysis

- Statistical design: Completely randomized design (CRD)
- Statistical analysis: One way ANOVA between fish pond owners and non-owners of each region. In addition, multivariate analysis will be done to connect socioeconomic indicators and family health. Test variables will include daily fish consumption, SIS consumption, height at age, weight at age, and weight at height for each participant.
- Null hypothesis: There are no differences in health indicators or fish consumption between participants who own fish ponds and those who do not own ponds.

Schedule

Since ponds are harvested mainly in the fall, our field surveys will be done from 1 September 2014 through 1 December 2014, with final reports due 30 August 2015.

ASSESSMENT OF MARKET OPPORTUNITIES FOR SMALL-SCALE FISHERS AND FARMERS IN CENTRAL UGANDA

Marketing, Economic Risk Assessment, and Trade/Study/13MER05AU

Collaborating Institutions and Lead Investigators

Alabama A&M University	James O. Bukenya
Makerere University (Uganda)	Theodora Hyuha

Objectives

1. Develop a marketing strategy and plan that identifies appropriate market segments and pricing mechanisms.
2. Describe actors, commodity flows and price formation in the marketing chain for Catfish and Tilapia for the reseller market.
3. Evaluate performance of the marketing system by calculating gross and net margins for the species studied.
4. Assess the critical factors affecting market performance and to propose policy recommendations for enhancing market performance

Significance

Review of past Sub-Saharan Africa research related to aquaculture reveals a strong production focus (Ogundari and Akinbogun, 2010; Onumah et al., 2009; Onumah and Acquah, 2010; Asamoaha et al., 2012), leaving many marketing questions unanswered. The need to place special emphasis on marketing research derives from the strategic challenges that the aquaculture industry faces. Like producers in many commodity industries, aquaculture producers are faced with dramatic increases in global supply (most especially in China), mature demand in the developed world, and falling prices overall. Industry profitability has suffered as a result.

Two broad strategies exist for responding to these forces. First, Ugandan aquaculture producers could focus their entire attention on becoming the low cost producers of their products and compete on the basis of price. Given some built-in cost disadvantages (high land, labor and feed costs) versus some other producing areas in the world, this strategy is not likely to be effective. Second, Ugandan producers could become much more consumer responsive in their marketing strategies and compete on the high level of consumer benefits that they deliver. For this strategy to succeed, much additional research is needed into all aspects of product marketing to differentiate their aquaculture products. Given inherent problems with the first strategic options, the second strategy of being consumer responsive appears to be a critical one for helping aquaculture producers reach business and profit goals. Marketing research to support this strategic option is thus crucial to increase income generation for small-scale fish farmers.

Quantified Anticipated Benefits

Analysis of processed (food) markets for aquaculture (primarily African Catfish and Tilapia) products will identify alternative production and marketing strategies for producers and processors and lead to increased economic returns.

- Increase sales and incomes for fish farmers
- Fish production become more market oriented and reduces post-harvest losses.
- Reduced marketing and other transaction costs for farmers.
- Improved market linkages and farm sales for farmed fish.

Study Design

The goal of the marketing and economic impact segment of the proposed aquaculture program is to identify and assess market opportunities for aquaculture products produced in the defined region.

Specifically, the market segment to be assessed is processed fish food products. Although African Catfish and Tilapia will be the primary focus, other species compatible to the region will also be included in the analysis. The study is designed to collect data from potential buyers of processed fish products and identify market opportunities for these products. The study will address specific issues including the identification of potential processed fish buyers, the location and needs of these buyers, determination of market size and potential demand, the potential for value-added products as well as the identification of potential barriers and possible solutions for overcoming these barriers. Discussions with aquaculture experts indicate that the best opportunity for small- and medium-sized operations in the region may be in niche markets. Thus, the value-added aspect is critical in identifying and developing strategic niche marketing opportunities. The following tasks will be undertaken to meet the objectives of the study.

Task 1: Survey fish buyers—wholesalers, restaurants, and retail outlets. A constraint to the growth of the Ugandan aquaculture industry is a lack of an organized effort to assist small- and medium-scale producers in developing marketing strategies and plans which lead to marketing programs designed to serve previously identified customer markets. Although a number of aquaculture studies have addressed some portions of this area, none have been found to be directly applicable to the market situation faced by Ugandan aquaculture producers (Chopak 1992: Pomeroy and Sheehan 1991; Frobish l991). More specifically, few have had as their objective the same scope of study as addressed here. The study will, therefore, provide information for the development of marketing strategies and a marketing plan for Ugandan aquaculturalists producing product for the reseller market. With this in mind, reseller organizations (wholesalers, retail buyers and restaurants), which buy and sell aquaculture products will comprise the sample selection for this task. Extensive use of the channels of distribution for the purchase of these products will be used to identify and select research participants. In this manner, the research will address value-added product potential from current users as well as possible opportunities for aquaculture products from those who do not currently purchase these products.

It should be noted that the market research focuses on organizational buyers rather than the ultimate end consumer. The reason for this is twofold: 1) our experience with other products in similar marketing situations has shown that it is extremely important to document the needs and behavior of the reseller market distributing to the region being targeted if producer success is to be realized; and 2) interviews of experienced aquaculturalists have indicated that successful niche marketing for Ugandan aquaculture products should begin with a thorough understanding of the reseller market if one is to thoroughly understand the barriers to the successful marketing of Ugandan aquaculture products. By analyzing resell buyers, barriers affecting the effective distribution of Ugandan aquaculture products can be identified and addressed. The specific activities to be undertaken, or already initiated, are:

The investigators have worked with appropriate organizations involved in aquaculture production and sales (e.g., WAFICO, NaFFIRRI, etc.) and have also met with aquaculture experts in the region, gaining valuable anecdotal insight into the needs and perspectives of these aquaculturalists.

The target population is Ugandan firms that purchase fish; wholesalers, retail buyers, and restaurants. The sample frame is developed from multiple sources including the WAFICO database. Wholesalers will be identified and selected from existing farm records, where possible. Restaurants and retail samples will also be selected from lists provided by farmers and several fish outlets in the region.

Although various forms of data collection are available (i.e., personal interviews and mad surveys), data will be collected in a two-step manner. Step one will include a limited number of personal interviews with current and potential aquaculture, organizational buyers.

Step two will be a telephone survey of a representative sample of the aquaculture organizational buying population. Although other methods are available, the most cost-effective research method for acquiring the necessary information and realizing the objectives of this study in the time frame allotted is a telephone interview method. The telephone survey method frequently provides the fastest turn around and does so with a minimum of interviewer bias.

Three questionnaires will be designed after receiving input from personal interviews with organizational buyers operating in the market for processed fish products. These questionnaires will be designed to ascertain the respondents' interest in purchasing aquaculture products as well as potential for value-added opportunities.

The data will be analyzed to determine the potential demand for aquaculture products, buyer requirements, and organizational buyer preferences for products and service. This will be done for all three reseller markets (wholesalers, retail buyers and restaurants) with comparisons made where appropriate.

Task 2: Analyze survey results to clarify m**arket segmentation, product placement, and pricing strategy.** The purpose of Task 2 is to use the analysis of the survey results to (a) identify potential aquaculture product buyers, (b) the location of these buyers, (c) assess the potential demand for aquaculture products, (d) determine customer requirements for aquaculture products, (e) customer preferences for products and service, and (f) the identification of and alternative solutions for overcoming barriers to Ugandan aquaculture production. *Customer is defined to mean organizational buyers or users and not the end consumer*. Under this task, we will identify marketing opportunities for Ugandan products in the food fish markets and to develop marketing strategy and a subsequent marketing plan to promote these opportunities. Market segmentation, product and strategy formulation for products with existing demand will be contrasted with those for new products and species. Commodity and niche markets will be contrasted. Pricing systems will be discussed, and policy implications inferred from these findings will be reported.

Task 3: Clarify costs, returns, value chains, and policy constraints. The focus of Task 3 is reducing marketing constraints which include both high costs and risk. High marketing costs often stem from poor transportation networks, lack of market information, and sometimes from lack of competitiveness in the market. These factors in turn can lead to highly variable prices. If these constraints can be addressed, farmers will earn more by specializing in species for which they have a comparative advantage. Given the increased importance of fish in nutritionally balanced diets, it will be important to have efficient marketing systems that reduce risk and allow higher prices for farmers and lower prices for consumers. By collecting and disseminating essential up to date data on costs and returns within the marketing systems, we can identify the most cost-effective options for improving marketing system performance and propose improved policies and better institutional support throughout the marketing chain. More specifically, the following activities will be accomplished:

- Existing marketing chains: we will describe existing marketing chains, including the types and numbers of actors and the flow of commodities and how farms of different sizes (small, medium and large) are involved.
- Costs, margins and profitability: we will quantify costs, margins and profitability of different stakeholders in the chain through collection of primary survey data. The estimation of costs will be comprehensive, including, but not limited to, depreciation on investment capital (e.g. trucks), interest on working capital, fuel costs, land and office costs and losses due to spoilage. Account will also be taken of multiple uses of some inputs, e.g. traders using their trucks to transport items other than the specified fish products. Special attention will be given to wholesale to retail margins, including any restrictions on movement of products that affect costs from wholesale to retail and to identify any barriers to entry for potential traders.
- Enhancing marketing system performance: we will identify implications and recommendation on policies to enhance marketing system performance in the region and countrywide.

<u>Schedule</u>

	2013	2014				2015			
	4th	1ST	2ND	3rd	4th	1ST	2ND	3rd	4th
Project set-up/Stakeholder Meeting									
Recruit Students/Develop linkages with partners									
Task 1									
Participant selection (organizational buyers)									
Develop three distinct survey questionnaires									
Pre-test questionnaires in respective markets									
Collect primary data (both metric and non-metric)									
Data entry and analysis using SPSS software									
Develop market-driven marketing strategy									
Task 2									
Identify potential aquaculture product buyers									

TOPIC AREA

WATERSHED AND INTEGRATED COASTAL ZONE MANAGEMENT

❖

ESTIMATING CARRYING CAPACITY FOR AQUACULTURE IN CAMBODIA

Watershed and Integrated Coastal Zone Management/Study/13WIZ01UC

Collaborating Institutions and Lead Investigators
University of Rhode Island — Dr. David Bengtson
Inland Fisheries Research and Development Institute (IFReDI) (Cambodia) — Dr. So Nam, Mr. Chheng Phen

Objective
To plan for sustainable aquaculture development in Cambodia by training Cambodian scientists, regulators/managers and officers in the use of models to estimate the amount of aquaculture waste that an ecosystem can assimilate.

Significance
The farming of fish in containment systems (cages, tanks, ponds, etc.) is based on raising them at higher densities than are normally found in nature and feeding them on pellet diets. That is, both the fish and the added feed represent additions of organic materials to a natural system. One key to sustainable aquaculture development is to be sure that the added organic materials do not overwhelm the capacity of the environment to assimilate the waste (or other) products resulting from the aquaculture operation. This can be done in a number of ways, e.g. limiting the inputs to the system, mitigating the waste outputs using mechanical or biological processes, and so on.

Unfortunately, there are plenty of examples from around the world of what happens to an environment when the assimilative capacities of the environment are exceeded. Broadly speaking, the impacts can alter the habitat, and therefore the ability of the natural community in that area to endure. Any aquaculture operation is going to have an impact on the environment, simply by virtue of being something different that has been added to a natural system. If a given operation becomes too large, or if one small operation triggers the installation of many copy-cat operators, the impact can be concomitantly larger and may end up destroying the ecosystem. Thus, the key to aquaculture development in an environmental context is to determine a) what impacts can be considered acceptable and what impacts are considered unacceptable, and consequently b) what levels of aquaculture production can be allowed in an area before unacceptable impacts are seen.

Ideally, before aquaculture production begins in a given region, a process of site selection is employed, often accompanied by modeling to estimate the suitability of site for production (e.g., will the temperature, dissolved oxygen, etc. allow the fish to grow well there) or for assimilative capacity for wastes (in the context of what someone, ideally stakeholders, identify as unacceptable impacts). Once aquaculture production begins, a monitoring program is usually put in place to verify that the modeling was correct (and in developed countries to ensure that the aquaculture operator is meeting the criteria of his permit). Unfortunately, in many areas of the world, aquaculture has proceeded apace before an appropriate regulatory structure has been established, so that an environment has already been impacted to greater or lesser degree.

The term "carrying capacity" originated in population ecology to mean the population number of a given species when dN/dt = 0 following logistic population growth (i.e., the population that the resource base can support). It has been adopted by aquaculture to mean something related, but still recognizably different. Aquaculture carrying capacity in general means the largest number (although more usually, biomass) of a species that can be grown in an area and there are several sub-definitions or qualifications. Physical carrying capacity is simply the largest number of organism and their containment structures that can physically fit in a given area. This is rarely seen, although some places in China come close. Production carrying capacity is the largest number of organisms that can be raised in an area before the food runs out (mostly applied to molluscan culture dependent on phytoplankton production). Ecological carrying capacity is the largest amount of production that can be achieved without unacceptable impacts on the environment (and the critical questions are: what is deemed to be unacceptable and who decides that?). Finally, social carrying capacity is the largest amount of production that can be achieved without unacceptable impacts on the human population (with the same questions as before).

A variety of models have been developed for aquaculture, including bioenergetic models to describe fish growth under various environmental conditions, hydrodynamic models to describe the transport of wastes given a set of hydrological conditions, inputs, etc. and ecosystem (trophic-web) models to predict the impacts of aquaculture production on other components of the ecosystem. Whatever the modeling approach chosen for a particular situation, it is critical that regulatory managers understand what the model is doing, accept the model as both realistic and useful, and are not overwhelmed by the model (i.e., it is not overly complicated or data-demanding). An associated critical factor is that the model is only as good as the data input to it. If only limited data are available, then the model will produce results with extremely large 'error bars" that limit its utility.

In late 2010, China became a net importer of seafood, even though it is by far the world's leading producer of aquaculture products. Since China's waters are already maximally used for aquaculture production, the most logical place for aquaculture production to expand to supply the Chinese market is Southeast Asia. Some places in Southeast Asia have already exceeded the capability of the surrounding environment to assimilate aquaculture wastes. The challenge for the future is to plan for sustainable aquaculture development in Southeast Asia (for both Chinese and local/regional markets) so that aquatic environments are not overwhelmed by aquaculture wastes.

During 2012, the Lead PI on this investigation assessed the needs and capabilities of government agencies for aquaculture carrying capacity modeling in Indonesia, Philippines, Thailand and Vietnam. That assessment identified many issues and needs common to all of the countries. For example, a) sufficient data to do complex ecosystem modeling is usually lacking, but one could do very simple mass-balance modeling that would be better than nothing, b) in all countries the control of aquaculture permits is at the municipal level, so that local officials need to be educated about aquaculture carrying capacity, and c) aquaculture production in many places is economically inefficient due to poor environmental practices and excessive fish mortality That first-year assessment has led to a second year of work, including expanding the coverage to Malaysia and Myanmar, as well as the convening of a regional workshop in June, 2013, so that scientists and regulators from key institutions in the various countries can work toward a regional approach to solving these over-capacity problems. The one country that is missing from this effort is Cambodia, although Host Country co-PI Chheng Phen attended the regional workshop in June 2013. As Cambodia develops its aquaculture industry, it could greatly benefit from being part of this regional effort.

Quantified Anticipated Benefits

This investigation will result in a suite of about 2,000 government regulators/managers and officers in Cambodia who have improved understanding of environmental carrying capacity, plus a smaller group of

100 scientists and researchers who can apply models to the calculation of carrying capacity for specific bodies of water. In the long-term, this should yield a more sustainable approach to aquaculture development in Cambodia than would be the case without this effort.

This investigation will also allow the Lead PI to expand his work in SE Asia on environmental carrying capacity for aquaculture. The U.S. soybean industry is very interested in this work in order to promote the rational development of aquaculture in the region. The Lead PI's previous efforts in this regard with six other SE Asian countries were funded by the United Soybean Board and the aforementioned regional workshop in June 2013 was funded by the U.S. Soybean Export Council.

Research Design and Activity Plan

Location of Work

IFReDI, Phnom Penh, Cambodia, Tonle Sap region in Kampong Chhnang), lower Mekong region in Kandal province/Phnom Penh), upper Mekong region in Kampong Cham province), and coastal region in Preah Sihanouk province

Methods

The Lead PI will provide training workshops and seminars at IFReDI to educate the staff(s) of relevant regulatory agencies on the problems behind unregulated aquaculture development and the uses of modeling to estimate aquaculture carrying capacity. Specific modeling approaches will include mass-balance models for freshwater bodies based on phosphorus levels, organic deposition models for accumulation of particles (such as uneaten feed and feces) from aquaculture operations, water quality models based on hydrodynamics for coastal waters, and trophic-web ecosystem models (Ecopath) for determination of ecological carrying capacity. Large groups of government employees will be educated via a train-the-trainer approach. We anticipate that the Lead PI will be able to train approximately 30-40 scientists and regulators in the Phnom Penh capital region during the initial workshops/seminars there in December 2013. While those presentations will be made in English, the trainees will be asked to convert the lessons learned into Khmer for further dissemination around the country. These trainees will then be able to train another 60-70 scientists and regulators in the provincial offices and laboratories to be able to a) understand the concepts of aquaculture carrying capacity, and b) do simple mass-balance modeling (see below). Finally, all of those trained people will be able to provide conceptual training to the fishery officers around the country. These fishery officers are the people in daily contact with wild-harvest fishers and aquaculturists nationwide. They do not need to know how to conduct the modeling, but they should be able to explain to fishers and farmers the concepts of environmental capacity for assimilating aquaculture wastes and the negative consequences (to the farmer and the environment) of exceeding that capacity. Given the preponderance of freshwater aquaculture in Cambodia and the likely paucity of data to incorporate into models, the primary modeling effort will be in mass-balance modeling. The first step will be identification of already collected data on water body volumes, inflow-outflow, ambient phosphorus concentrations, FCR data for fish, and phosphorus content of feed. Where more data are needed, Cambodian scientists will collect them. Finally, Cambodian scientists will apply the mass-balance models to specific sites in Cambodia where aquaculture is ongoing, including Kampong Chhnang province (Tonle Sap region); Kandal province and Phnom Penh (lower Mekong region); Champong Cham province (upper Mekong region) and Preah Sihanouk province (Coastal region).

A secondary effort will be the examination of potential coastal aquaculture in Cambodia and the identification of the best modeling approaches that should be used as part of decision support systems for locating aquaculture in the marine environment.
In June 2015, a workshop will be held in Phnom Penh to bring together the results of the site-specific modeling efforts from around the country. The Lead PI will conduct this workshop in association with Host Country PI's, with the aim compiling a list of lessons learned and determining if there are Cambodian national themes related to aquaculture carrying capacity that should be investigated further.

Schedule

The duration of implementation of this proposed investigation will be 24 months, starting from 1 October 2013 till 30 September 2015.

- December, 2013 – Lead PI will present seminars in Phnom Penh, just before/after the Asia- Pacific Aquaculture conference in Ho Chi Minh City, and begin work with Cambodian scientists.
- January – December 2014 – Cambodian scientists will gather data and apply mass-balance models to existing aquaculture areas (See Section f).
- January 2015 – June 2015 – Final report writing and organizing consultation and dissemination workshop on research findings

Deliverables

The PowerPoint presentation used in the training seminar by the Lead PI in Phnom Penh will be made available to all participants and to their agencies within the Cambodian government. Trainees from Phnom Penh can use this directly, or translate the English into Khmer for presentation to provincial officials. A fact sheet will be developed (originally in English, but then translated into Khmer) for dissemination to the fishery officers around the country. At the end of the project, a peer-reviewed publication will be developed to describe the process and outcome of this project.

TOPIC AREA

MITIGATING NEGATIVE ENVIRONMENTAL IMPACTS

❖

NOVEL APPROACH FOR THE SEMI-INTENSIVE POLYCULTURE OF INDIGENOUS AIR-BREATHING FISH WITH CARPS FOR INCREASING INCOME AND DIETARY NUTRITION WHILE REDUCING NEGATIVE ENVIRONMENTAL IMPACTS

Mitigating Negative Environmental Impacts/Experiment/13MNE01NC

Collaborating Institutions and Lead Investigators

Bangladesh Agricultural University (Bangladesh)	Md. Abdul Wahab Shahroz Mahean Haque Sadika Haque
North Carolina State University (USA)	Russell Borski

Objectives

1. Assess reduced-feeding strategies for combined polyculture of two major carps (*Rohu* and *Catla*) with Shing catfish or Koi in semi-intensive pond culture. Culture of carp with these fishes would represent a new polyculture technology in Bangladesh.
2. Identify the feed-reduction strategy and carp stocking ratios needed for equivalent or better production yields through increased nutrient utilization efficiency.
3. Evaluate overall performance and economic returns of the improved management strategy and transfer of findings to local farmers through an extension workshop. We estimate the attendance of 100 individuals.

Significance

Carps are the dominant finfish cultivated in Bangladesh, with multiple species farmed together in polyculture. Studies suggest that cultivation of other finfish varieties, particularly indigenous species with high mineral content, will be important steps for increasing the yield and diversity of aquaculture products for consumption in Bangladesh, and in reducing some types of dietary malnutrition, such as iron-deficient anemia (Dey *et al.*, 2008; Micronutrient Initiative/UNICEF, 2004). Indigenous air-breathing fishes, such as Shing catfish (*Heteropneustes fossilis*) and koi (climbing perch, *Anabas testudineus*) have been successfully cultivated in Bangladesh in recent years and command a high market value (DOF, 2012; Kohinoor *et al*., 2011). Both are currently in great demand by consumers for their taste and nutritional value (Hasan *et al.,* 2007, Vadra, 2012; Vadra and Sultana, 2012). Shing catfish is particularly high in both iron (226 mg 100 g^1) and calcium relative to other freshwater fishes, and has been recommended in the diets of the sick and convalescent (Saha and Guha, 1939; Singh and Goswami, 1989). This investigation seeks to promote production of finfish with high nutritional value (Shing, Koi), while improving both economic profitability and environmental water quality through implementation of better management practices.

Air-breathing fishes provide a significant advantage for pond culture, as they tend to be resilient to harsh conditions, particularly during periods of low-oxygen, which can occur with high temperatures or drought. Currently, production of Shing and Koi is limited to monoculture systems with intensive use of commercial-grade feeds (30-35% crude protein). As feed can comprise up to 60% of total production costs, the current practices for these fish limit participation by small homesteads and therefore comprise a significant impediment to further expansion of this industry. Further, the use of high-levels of feed inputs has led to a persistent deterioration of pond water quality (eutrophication; cf. Chakraborty and Mirza, 2008; Chakraborty and Nur, 2012) and periodic mass mortalities and disease outbreaks. As most ponds are located near homesteads and villages, poor water quality and foul odors related to greater nutrient-loading impacts both local health and socio-economic tensions within the community (personal communication, Nural Amin, local farmer in Tarakanda, Mymensigh, July, 2012). Through field visits to Mymensingh, this research team (Wahab and Borski) observed firsthand that most air-breathing fish farms are often overfed, therefore some of the problems associated with farming of air-breathing fishes can be alleviated through better management and implementation of semi-intensive culture practices. These problems may be mitigated through polyculture, where excess nutrients and algae can be utilized by other species (*e.g.*, carp). This investigation will evaluate whether carps can be incorporated into the culture of indigenous air-breathing fishes, Shing catfish and Koi. As carps feed primarily upon primary production (phytoplankton/algae; Wahab *et al.,* 2002), their incorporation may significantly reduce negative impacts associated with the farming of air-breathing fishes, while also allowing for greater production yields and the availability of additional fish for home consumption.

An additional mechanism for mitigating excess nutrient inputs is to limit the amount of feed applied in Shing and Koi culture. We have previously shown that equivalent production yields of tilapia can be achieved with 50% less feed either provided as a full ration on alternate days or as a lower daily rate (Bolivar et al. 2006; Borski *et al*., 2011). Similarly, alternate day feeding significantly improves feed conversion and reduces costs in the grow-out of milkfish in ponds and seacages (DeJesus-Ayson and Borski, 2012). Feed-restriction has not been evaluated in Shing catfish or Koi production, however previous work in catfish (US and Asian varieties) suggests Shing may also undergo periods of compensatory growth (SRAC, 1989; Zhu et al., 2005). In particular, Sutchi catfish (*Pangasianodon hypophthalmus*) raised on alternate-day feed regimens (50% feed reduction) had little differences in production yield compared to fish fed daily, yet net profits were increased 99% through the reductions in feed and labor costs (Amin et al., 2012). This investigation will evaluate whether reduced-feeding protocols can be successfully applied to the polyculture of Shing catfish/carp or Koi/carp. Reductions in feed and overhead costs, combined with mixed-trophic level nutrient utilization, may make semi-intensive culture of Shing catfish and Koi more feasible for greater adoption among farmers while also mitigating environmental impacts associated with nutrient loading. The results of these findings will be reported directly to local farmers and extension agencies by presentation at a local farmer's day event as well as through a an AquaFish Innovation Lab Project Workshop in conjunction with all other project results.

Quantified Anticipated Benefits

1. Use of a mixed-trophic level polyculture production system will increase nutrient utilization efficiency and reduce negative environmental and social impacts (pond eutrophication) of producing Shing catfish and Koi.
2. We anticipate that semi-intensive polyculture of high-value Shing catfish and Koi with carp will improve earned incomes through greater yield of fishes and promote more sustainable production of fish with high nutritional value.
3. Successful implementation of feed-reduction strategies for Shing catfish/carp and Koi/carp polyculture will reduce feed costs by as much as 50%, thereby increasing production of high-value crops as farming of these fish will become more attractive to low-income homestead farmers.
4. The availability, quality, and nutritional benefit of these fishes for local consumption will be enhanced through greater production levels with better management practices.
5. Rapid transfer of these findings to an estimated 100 farmers local farmers and extension agents through a farmer's day training workshops will foster a better understanding of integrative polyculture and how it may be successfully used to reduce costs and minimize negative environmental impacts.
6. Three-four graduate and undergraduate students at BAU will receive training and education on airbreathing/carp polyculture and feed management strategies.

Plan of Work

Location

These studies will be performed onsite at the Fisheries Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh. Water quality analysis will be performed at the Water Quality and Pond Dynamics Laboratory (BAU). Dr. Sadika Haque at the Dept. of Agricultural Economics (BAU) will conduct the economic analysis for this study.

Methods

1. Assess reduced-feeding strategies for combined polyculture of two major carps (*Rohu* and *Catla*) with Shing catfish.

This study will evaluate two 50% feed reduction strategies, daily half-rations or alternate-day full rations, to identify the method yielding better economic returns for semi-intensive carp/catfish polyculture production. We will test the effects of full or reduced-feeding (2) on growth, production yield, and economic profitability (cost-benefit analysis) to minimize both costs and mortality due to poor water quality. As an additional benefit, this design will also test whether the current practice of intensive Shing farming could be better managed (reductions in eutrophication) by the addition of carps. Two Indian carps, *Rohu* (*L. rohita*) and *Catla* (*C. Catla*), will be raised with Shing catfish (*H. fossilis*) in mixed-culture ponds. The feed reduction strategies will be implemented using the following experimental design:

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Rohu (*L. rohita*)	0	80 (0.8/m^2)	80 (0.8/m^2)	80 (0.8/m^2)
Catla (*C. catla*)	0	20 (0.2/m^2)	20 (0.2/m^2)	20 (0.2/m^2)
Shing (*H. fossilis*)	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)
Fertilization	0	0	4:1 (N: P)	4:1 (N: P)
Feeding Protocol	100% satiation daily	100% satiation daily	50% satiation daily	100% satiation alternate-day
Replicates (*n*)	4	4	4	4

This design contrasts the current practice of intensive Shing catfish farming (T1), against treatments incorporating carps under intensive culture (T2), or semi-intensive culture with alternate reduced-feeding/fertilization strategies (T3, T4). As carp farming requires significant primary production, levels that may not be achieved under restricted feeding, ponds will be fertilized weekly for these groups (T3, T4). As fertilizer is roughly 14% of feed costs, it is anticipated this design will prove more efficient and profitable than with full-feeding alone (T1, T2). The treatment groups will be randomly assigned to ponds (N =16, 100 m^2, 1.5 m depth). Prior to flooding and stocking, the ponds will be dried, re-excavated, and limed (25 g $CaCO_3/m^2$). The will be fertilized initially at 28 kg N and 5.6 kg P/ha prior to stocking.

During the production period (120 days), T3 and T4 ponds will be fertilized at a rate of 28 kg N/ha/week and 5.6 kg P/ha/week. Full rations of feed (30% CP, commercial grade) will be administered by feeding to satiation, determined empirically as outlined under investigation 1. The reduced-feeding groups will receive 50% less feed (either daily half-rations or alternate-day full rations, based on values derived from T1-2). Feed amounts will be recorded for cost-benefit analysis performed at the end of study. All ponds will be sub-sampled every 14 days to collected growth data (mean fish length and weight). Water quality will be monitored daily (dO2, pH, turbidity/ secchi-disk depth), while additional parameters will be measured weekly by the Water Quality and Pond Dynamics Laboratory at BAU: ammonia, nitrates, total phosphate, and alkalinity. Production yields (market weight, kg), estimated market returns, feed input costs (feed, fertilizers, labor, fingerlings), and labor costs will be gathered for all treatment groups at the end of study for marginal cost-benefit analysis by Dr. Sadika Haque (BAU). All treatments will be tested for significant differences in growth (mean length, weight X time), growth efficiency (specific growth

rate, feed conversion ratio), and water quality using Analysis of Variance ($p < 0.5$; preplanned contrasts: T1 with T2, T2 with T3 and T4; T3 vs T4).
Null Hypothesis: No differences in growth efficiency, water quality, or economic returns are observed with Shing farming with inclusion of carps under intensive culture practices (no pond fertilization) or semi-intensive culture with fertilization/reduced feeding strategies.

2. Effect of stocking density for koi/carp polyculture using the feeding-fertilization strategy developed for Shing catfish.
This study will assess whether the best feeding/fertilization strategy identified for Shing catfish (Study 1) could be implemented for polyculture production of air-breathing Koi (*Anabas testudineus*) with Indian carps (*Rohu* and *Catla*). As production of only one carp may prove useful under reduced-feeding (T3-T4; Study 1), we will also test different stocking levels for these two carps. The following experimental design is proposed:

Parameter	Treatment 1	Treatment 2	Treatment 3
Rohu (*L. rohita*)	80 (0.8/m^2)	100 (1.0/m^2)	none
Catla (*C. catla*)	20 (0.2/m^2)	none	100 (1.0/m^2)
Koi (*A. testudineus*)	500 (5.0/ m^2)	500 (5.0/ m^2)	500 (5.0/ m^2)
Fertilization/Feeding	Best of T2-T4, Expt. 1	Best of T2-T4, Expt. 1	Best of T2-T4, Expt. 1
Replicates (*n*)	4	4	4

The treatment groups will be randomly assigned to ponds (N = 12, 100 m^2, 1.5 m depth). The best feeding/fertilization strategy identified for Shing catfish (T2-T4; Expt. 1) will be implemented for all treatment groups. The preparation of ponds, fertilization rates, and sample collection (growth data, water quality parameters) will be performed as described in Expt. 1. As outlined in Expt 1., the final production yields (market weight, kg), estimated market return, feed and labor costs will be determined at the end of study for an additional cost-benefit analysis by Dr. Sadika Haque (BAU). Treatments will be tested for significant differences in growth (mean length, weight X time), growth efficiency (specific growth rate, feed conversion ratio), and water quality using Analysis of Variance ($p < 0.5$).
Null Hypothesis: No differences in growth efficiency, water quality, or economic returns are observed with Koi-mixed Rohu/Catla polyculture when using either Rohu or Catla alone under semi-intensive culture with fertilization-reduced feeding strategies.

3. Evaluation of study findings and reporting to local extension agencies and farmers.
The marginal cost-benefit for Experiments 1 and 2 (BAU) will address whether semi-intensive polyculture of Shing catfish and/or Koi farming with Indian carps is economically more profitable and can dramatically reduce costs so even the smallest farmholders might adopt the practice. Water quality analyses will determine the potential environmental benefits of the new semi-intensive polyculture technology on Shing/Koi culture. Results will be presented to representatives from local extension agencies for further consideration and promotion to rural farmers. Perceived benefits from this analysis, including increased fish production, greater cost savings, market profitability, and feasibility for semi-intensive culture, along with promoting greater consumption of fish with high nutrient content (e.g., Shing and Koi), will be extended to rural farmers through presentations at a local farmer's day event. The research outcomes will also be disseminated through production of an extension factsheet in the local language for wider outreach to farmers, extension agencies of the government, and NGOs.

Schedule
Mar 2014 - Jun 2014: Study 1, evaluation of reduced-feeding strategies for Shing / carp polyculture.
Mar 2015 - July 2015: Study 2, Koi / carp polyculture under optimal reduced-feeding strategy
July 2015 - Sept 2015: Presentation at farmer's day event along with the tilapia-carp polyculture research;

Presentation at the AquaFish Innovation Lab Project Workshop in conjunction with all other project results; final technical report

Deliverables

1. Improvements in Environmental Water Quality – Water quality parameters will be reported for all ponds used in Studies 1-2, and tested for significant differences. We anticipate highly significant improvements in environmental water quality for the culture of Shing catfish with carp. Further improvements are likely to occur with reduced feeding, semi-intensive culture practices.
2. Improvements in Production Yield – Total production yields (kg) and estimated market return will be reported for all treatment groups in Studies 1-2. We anticipate modest improvement (~10-20% increase) in total production yield and market return through the addition of carps and less stock mortality due to improved water quality.
3. Improvements in Human Nutrition –We anticipate greater production yields (kg) of fish identified in Item 2 will benefit human nutrition, as it will enhance income and availability of fish for rural farming households. This is particularly true of Shing catfish as they are high in micronutrients commonly lacking in the diet of rural Bangladeshis.
4. Documentation and Dissemination – The findings from Studies 1-2 will be reported through the Technical Reports of the AquaFish Innovation Lab, the scientific proceedings of the World Aquaculture Society Annual meeting, and peer-reviewed literature. Three-four undergraduate and graduate students will receive training on management strategies related to Shing/Koi catfish culture and reduced feeding strategies in aquaculture. One hundred local farmers, extension agents or other stakeholders will receive training on the results and benefits of these studies through a farmer's day workshop. The research outcomes will also be disseminated through production of an extension factsheet in the local language for wider outreach to farmers, extension agencies of the government, and NGOs. Presentation of benefits derived from this investigation will be presented at the AquaFish Innovation Lab Project Workshop to be held at the end of the project.

APPENDIX I: LITERATURE CITED

Literature Cited, North Carolina State University

Investigation 1

Abdelghany, A.E. and Ahmad, M.H. 2002. Effects of feeding rates on growth and production of Nile tilapia, common carp and silver carp polycultured in fertilized ponds. Aquacult. Res., 33:415-423.

ADB (Asian Development Bank). 2005. An evaluation of small-scale freshwater rural aquaculture development for poverty reduction. 163 pp

Azim, M.E., M.A. Wahab, A.H.M. Kamal, Z.F. Ahmed and M.C.J. Verdegem. 2004. Feeding relations of silver barb, *Barbodes gonionotus* (Bleeker) with major Indian and common carp and its effect in fish production in a polyculture system. J. World Aqua. Soc., 35 (1), 100-108.

American Public Health Association (APHA), the American Water Works Association (AWWA) and the Water Environment Federation (WEF). 2012. Standard Methods for the Examination of Water and Wastewater, 22nd edition. APHA, Washington, DC.

Belton, B., Karim, M., Thilsted, S., Murshed-E-Jahan, K., Collis, W., Phillips, M., 2011. Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center. November 2011.

Bolivar, R.B., C.L. Brown and E.T. Jimenez. 2003. Feeding Strategies to Optimize Tilapia Production in Ponds. Book of Abstract. Aquaculture 2003. Louisville, Kentucky, USA. p. 26.

Bolivar, R.B., Jimenez, E.B.J. and Brown, C.L. 2006. Alternate day feeding strategy for Nile tilapia growout in the Philippines: Marginal cost-revenue analysis. North American Journal of Aquaculture, 68: 192-197.

Bolivar, R.B., Vera Cruz, E.M, Jimenez, E.B.T, Sayco, RMV, Argueza, R.L.B, Ferket, P.R., Stark, C.R., Malheiros, R., Ayoola, A.A., Johnstone, W.M., Picha, M.E., Holler, B.L., Won, E.T., and R.J. Borski. 2010. Feeding reduction strategies and alternative feeds to reduce production costs of tilapia culture. Technical Reports: Investigations 2007-2009, AquaFish Collaborative Research Support Program. Oregon State University. Vol 1. p 50-78.

Dey, M.M., Bose, M.L., Alam, M.F., 2008. Recommendation domains for pond aquaculture. Country case study: Development and status of freshwater aquaculture in Bangladesh. WorldFish Center Studies and Reviews No. 1872. The WorldFish Center, Penang, Malaysia. 73p.

Diana, J.S., Lin C.K and Jaiyen K. 1994. Supplemental feeding of tilapia in fertilized ponds. J. World Aqua. Soc. 25:497-506

Egna, H.S. and C.E. Boyd (editors). 1997. Dynamics of Pond Aquaculture. CRC Press. Boca Raton, FL 471 pp.

El-Sayed, A.F.M. 2006. Tilapia Culture. CABI Publishing, Oxford, U.K. 277 pp.

Food and Agriculture Organization of the United Nations, 2012. The state of food security in the world 2012: economic growth, hunger, and malnutrition. Rome, 2012. Available online at: http://www.fao.org/docrep/016/i3027e/i3027e00.htm

Green, B.W. and Duke, C.B. 3rd., 2006. Chapter 7. Pond production. pp 253-288 *In* Lim, C.E., Webster, C.D. *eds*. Tilapia: biology, culture, and nutrition. Haworth Press, N.Y. 678 p.

Khouriaiba, H.M., El-Sherif, M.S. and Dansoury, M.A.K. (1991). Enhanced fish production through polyculture system of Nile tilapia (*Tilapia nilotica*) with Common carp (*Cyprinus carpio*) in floating cages. Zagazig Vet. J., 19(4):854-864.

Lin, C.K. and Yi, Y. (2003). Minimizing environmental impacts of freshwater aquaculture and reuse of pond effluents and mud. Aquaculture, 226: 57-68.

El-Sayed, A.F.M. 2006. Tilapia Culture. CABI Publishing, Oxford, U.K. 277 pp.

Wahab, M.A., Rahman M.M. and Milstein A. (2002). The effect of common carp, *Cyprinus carpio* (L.), and mrigal, *Cirrhinus mrigala* (Hamilton), as bottom feeders in major Indian carp polycultures. Aquaculture Research, 33:547-557.

Investigation 2

Al-Harbi, A.H., Uddin, M.N., 2004. Seasonal variation in the intestinal bacterial flora of hybrid tilapia (Oreochromis niloticus X Oreochromis aureus) cultured in earthen ponds in Saudi Arabia. Aquaculture 229, 37–44.

Al-Harbi, A.H., Uddin, N., 2005. Bacterial diversity of tilapia (Oreochromis niloticus) cultured in brackish water in Saudi Arabia. Aquaculture 250, 566– 572.

Bairagi, R., 1980. Is income the only constraint on child nutrition in rural Bangladesh? Bulletin of the World Health Organization 58(5): 767-772.

Belton, B., Karim, M., Thilsted, S., Murshed-E-Jahan, K., Collis, W., Phillips, M., 2011. Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center. November 2011.

Bolivar, R.B. Brown, Jimenez, E.B.J. and Brown, C.L. 2006. Alternate day feeding strategy for Nile tilapia growout in the Philippines: Marginal cost-revenue analysis. North American Journal of Aquaculture, 68: 192-197.

Borski, R.J., Bolivar, R.B., Jimenez, E.B.T., Sayco, R.M.V., Arueza, R.L.B., Stark, C.R., Ferket, P.R., 2011. Fishmeal-free diets improve the cost effectiveness of culturing Nile tilapia (Oreochromis niloticus, L.) in ponds under an alternate day feeding strategy. CRSP Aquafish Proceedings, Shanghai, China.

Bröer, S., 2008. Amino acid transport across mammalian intestinal and renal epithelia. Physiol Rev 88, 249-286.

Cleveland, A., and Montgomery, D.L., 2003. Gut characteristics and assimilation efficiencies in two species of herbivorous damselfishes (Pomacentridae: *Stegastes dorsopunicans* and *S. planifrons*). Marine Biology 142: 35-44.

De Filippo, C., Cavalieri, D., Di Paola, M., Ramazzotti, M., Poullet, J.B., Massart, S., Collini, S., Pieraccini, G., Lionetti, P., 2010. Impact of diet in shaping gut microbiota revealed by a comparative study in children from Europe and rural Africa. Proc Natl Acad Sci U S A 107(33), 14691-14696.

De Jesus-Ayson E.G.T., Borski., 2012. Ration Reduction, Integrated Multitrophic Aquaculture (Milkfish-Seaweed-Sea Cucumber) and Value-Added Products to Improve Incomes and Reduce the Ecological Footprint of Milkfish Culture in the Philippines, p 320-335. Technical Reports: Investigations 2009-2011, AquaFish Collaborative Research Support Program. Oregon State University. Vol 2. 414 pp

Dey, M.M., Bose, M.L., Alam, M.F., 2008. Recommendation domains for pond aquaculture. Country case study: Development and status of freshwater aquaculture in Bangladesh. WorldFish Center Studies and Reviews No. 1872. The WorldFish Center, Penang, Malaysia. 73p.

Farmanfarmaian, A., Sun, L.Z., 1999. Growth hormone effects on essential amino acid absorption, muscle amino acid profile, N-retention and nutritional requirements of striped bass hybrids. Genet Anal 15(3-5), 107-113.

Food and Agriculture Organization of the United Nations, 2013. Species fact sheet: Oreochromis niloticus. Rome, 2013. Available online at: http://www.fao.org/fishery/species/3217

Food and Agriculture Organization of the United Nations, 2012. The state of food security in the world 2012: economic growth, hunger, and malnutrition. Rome, 2012. Available online at: http://www.fao.org/docrep/016/i3027e/i3027e00.htm

Heikkinen, J., Vielma, J., Kemiläinen, O., Tiirola, M., Eskelinen, P., Kiuru, T., Navia-Paldanius, D., von Wright, A., 2006. Effects of soybean meal based diet on growth performance, gut histopathology and intestinal microbiota of juvenile rainbow trout (Oncorhynchus mykiss). Aquaculture 261, 259-268.

Hulcr, J., Latimer, A.M., Henley, J.B., Rountree, N.R., Fierer, N., Lucky, A., Lowman, M.D., Dunn, R.R., 2012. A jungle in there: bacteria in belly buttons are highly diverse, but predictable. PLOS One 7(11): e47712.

Hussain, M.G., 2009. A future for the tilapia in Bangladesh. AQUA Culture Asia-Pacific Magazine July/August 2009, 38-40.
Gupta, M., Ahmed, M., Bimbao, M.A.P., Lightfoot, C., 1992. Socioeconomic impact and farmer's assessment of Nile tilapia (*Oreochromis niloticus*) culture in Bangladesh. ICLARM Tech Rep 35, 1-50.
Kashiwada, K., Teshima, S., 1966. Studies on the production of B vitamin by intestinal bacteria of fish: I. nicotinic acid, pantothenic acid and B_{12} in carp. Bull Jap Soc Sci Fish 32, 961-966.
Lozupone, C., Hamady, M., Knight, R., 2006. UniFrac--an online tool for comparing microbial community diversity in a phylogenetic context. BMC Bioinformatics 7, 371
Mandal, S.C., Hasan, M., Rahman, M.S., Manik, M.H., Mahmud, Z.H., Islam, S., 2009. Coliform bacteria in Nile tilapia, *Oreochromis niloticus* of Shrimp-*Gher*, pond and fish market. World J Fish Mar Sci 1(3), 160-166.
Nayak, S.K., 2010. Role of gastrointestinal microbiota in fish. Aquacult Res 41, 1553-1573.
Phillips, M., 2013. Improving aquaculture feed in Bangladesh. World Fish Aquaculture Feeds Workshop, April 4th, BRAC Center, Dhaka Bangladesh.
Picha, M.E., Silverstein, J.T., Borski, R.J., 2006. Discordant regulation of hepatic IGF-I mRNA and circulating IGF-I during compensatory growth in a teleost, the hybrid striped bass (*Morone chrysops* x *Morone saxatilis*). Gen Comp Physiol 147(2), 196-205.
Robinson, E.H., Lovell, A.T., 1978. Essentiality of biotin for Channel catfish (*Ictalurus punctatus*) fed lipid and lipid-free diets. J Nutr 108(10), 1600-1605.
Santigosa, E., García-Meilán, I., Valentin, J.M., Pérez-Sanchez, J., Médale, F., Kaushik, S., Gallardo, M.A., 2011. Modifications of intestinal nutrient absorption in response to dietary fishmeal replacement by plant protein sources in sea bream (*Sparus aurata*) and rainbow trout (*Onchorynchus mykiss*). Aquaculture 317, 146-154.
Sugiura, S., 2009. Identification of intestinal phosphate transporters in fishes and shellfishes. Fish Sci 75, 99-108.
Thillaimaharani, K.A., Logesh, A.R., Sharmila, K., Magdoom, K., Kalaiselvam, M., 2012. Studies on the intestinal bacterial flora of tilapia *Oreochromis mossambicus* (Peters, 1852) and optimization of alkaline protease by *Virgibacillus pantothenticus*. J Microbiol Antimicrob 4(5), 79-87.
Titus, E., Karasov, W.H., Ahearn, G.A., 1991. Dietary modulation of intestinal nutrient transport in the teleost fish tilapia. Am J Physiol - Reg, Integr Comp Physiol, 261:R1568-R1574.
Unites States Agency for Internal Development, 2012. Feed specialist lends hand to Bangladesh. First Person Press Report, June 05, 2012. http://www.usaid.gov/sites/default/files/success/files/fp_bangladesh_poultry.pdf
Welker, T.L., Lim, C., 2011. Use of probiotics in diets of tilapia. J Aquac Res Devel, S1-14
Zapata, A.A., 2013. Antimicrobial activities of lactic acid bacteria strains isolated from Nile tilapia intestine (*Oreochromis niloticus*). J Biol Life Sci 4(1), 164-171.

Investigation 3

Alam M.A., Rahman L., Khan M.M.R. and Rahman S.M.Z. (2006). Allozyme marker for the analysis of genetic variation of cross Koi (♀ local x ♂ Thai) *Anabus testudineus* with their parents. J Mol. Biol. and Biotech 4:9-12
Amin, A.K.M.R., Ashafrul, M.A.I., Kaderw, M.A., Bulbul, M., Hossain, M.A.R., Azim, M.E., 2012. Production performance of sutchi catfish *Pangasianodon hypophthalmus* S. in restricted feeding regime: effects on gut, liver and meat quality. Aquaculture Research 43: 621–627
Bolivar, R.B. Brown, Jimenez, E.B.J. and Brown, C.L. 2006. Alternate day feeding strategy for Nile tilapia growout in the Philippines: Marginal cost-revenue analysis. North American Journal of Aquaculture, 68: 192-197.
Borski, R.J., Bolivar, R.B., Jimenez, E.B.T., Sayco, R.M.V., Arueza, R.L.B., Stark, C.R., Ferket, P.R., 2011. Fishmeal-free diets improve the cost effectiveness of culturing Nile tilapia (*Oreochromis*

niloticus, L.) in ponds under an alternate day feeding strategy. CRSP Aquafish Proceedings, Shanghai, China.

Department of Fisheries, 2012. Fish Week Compendium. *Matshya Shakalon.*Department of Fisheries. Ministry of Fisheries and Livestock.

De Jesus-Ayson E.G.T., Borski., 2012. Ration Reduction, Integrated Multitrophic Aquaculture (Milkfish-Seaweed-Sea Cucumber) and Value-Added Products to Improve Incomes and Reduce the Ecological Footprint of Milkfish Culture in the Philippines, p 320-335. Technical Reports: Investigations 2009-2011, AquaFish Collaborative Research Support Program. Oregon State University. Vol 2. 414 pp

Dey, M.M., Bose, M.L., Alam, M.F., 2008. Recommendation domains for pond aquaculture. Country case study: Development and status of freshwater aquaculture in Bangladesh. WorldFish Center Studies and Reviews No. 1872. The WorldFish Center, Penang, Malaysia. 73p.

Chakraborty, B.K. and Mirza, M.J.A. (2008). Growth and yield performance of threatened Singi, *Heteropneustes fossilis* (Bloch) under semi intensive aquaculture. J. Fish. Soc. Taiwan 35: 117-125.

Chakraborty B.K. and Nur N.N. (2012). Growth and yield performance of Shingi, *Hetoropneustes fossilis* and Koi, *Anabus testudineus*, in Bangladesh under Semi-intensive culture systems. Int. J. Agril. Res. Innov. and Tech., 2 (2): 15-24.

Hasan M., Khan M.M.R. and Rahman A. (2007). Some biological aspects of Thai Koi, *Anabus testudineus* (Bloch). J. of Bangla. Agril. Univ., 5(2): 385-392.

Kohinoor A.H.M., Jahan D.A., Khan M.M., and Hossain M.G. (2011). Induced Breeding of Koi (*Anabus testudineus*) and its culture management. Ed: Director General, Bangladesh Fisheries Research Institute (BFRI), Mymenshingh. (Booklet*: In Bengali).*

Micronutrients Initiatives/UNICEF, 2004. Vitamin A and mineral deficiency: A global report. Ottawa, Canada

Saha K.C. and Guha B.C. (1939). Nutritional investigation on Bengal fish. *Indian J. Medical Res.,* 26: 921-927.

Singh M.P. and Goswami U.C. (1989). Studies on age and growth of an air-breathing catfish *Heteropneustes fossilis* (Bloch). J. Inland Fish. Soc. India, 21: 17-24.

Southern Regional Aquaculture Center (U.S.), 1989. Restricted feeding regimes increase production efficiency in Channel catfish. SRAC Publication No. 189

Vadra A. and Sultana N. (2012). Induced Breeding of Shing (*Heteropneustes fossilis*) and its culture management. Fish Culture and Management Technology Guidelines. Ed: Director General, Bangladesh Fisheries Research Institute (BFRI), Mymenshingh. *Pp 7-10 (In Bengali).*

Vadra A. (2012). Seed production and culture management of Shing (*Heteropneustes fossilis*). Ed: Director General, Bangladesh Fisheries Research Institute (BFRI), Mymenshingh. (Booklet*: In Bengal.)*

Wahab M.A., Rahman M.M. and Milstein A. (2002.) The effect of common carp, *Cyprinus carpio* (L.), and mrigal, *Cirrhinus mrigala* (Hamilton), as bottom feeders in major Indian carp polycultures. Aquaculture Research, 33:547-557.

Zhu, X., Shouqi, X.T., Wu, L., Yibo, C., Yunxia, Y., Wootton, R.J., 2005. Compensatory growth in the Chinese longsnout catfish, *Leiocassis longirostris*, following feed deprivation: Temporal patterns in growth, nutrient deposition, feed intake and body composition. Aquaculture 248: 307– 314

Investigation 4

Ahmed N., Alam, M.F. and Hasan, M.R. (2010). The economics of sutchi catfish (*Pangasianodon hypophthalmus*) aquaculture under three different farming systems in rural Bangladesh. Aquaculture Research, 41: 1668-1683.

Ali, H., Haque, M.M. and Belton, B. (2013). Striped Catfish, *Pangasius* aquaculture in Bangladesh: an overview. Aquaculture research, 44: 950-965.

Castaneda, R., Montoya-Ospina, R., McGee, M., Velasco, M. (2010). *Pangasius* juveniles tolerate moderate salinity in test. Global Aquaculture Advocate March/April 2010, 27-28.

David, A. (1962). Brief taxonomic account of the Gangetic *Pangasius pangasius* (Ham.) with description of a new sub-species from the Godavari. Proc. Indian Acad. Sci., 34(3): 136-156.

Edwards, P. and Hossain, M.S. (2010). Bangladesh Seeks Export Markets for Striped Catfish. *Global* Aquaculture Advocate, May-June, 65-68.

Halls, A.S., and M. Johns. (2013). Assessment of the vulnerability of the Mekong Delta *Pangasius* catfish industry to development and climate change in the Lower Mekong Basin. Report prepared for the Sustainable Fisheries Partnership, January 2013, 95pp.

Munir, S.A.M. (2009). Socio-economic impacts and sustainability of Pangasius (P*angasianodon hypophthalmus*) farming in Trishal Upazila under Mymensingh, Bangladesh. MS thesis, Institute of Aquaculture, University of Stirling, Stirling, Scotland, UK.

Rahman, A.K.A. (2005). *Freshwater Fishes of Bangladesh*, 2nd edition, Zoological Society of Bangladesh, Department of Zoology, University of Dhaka, Dhaka-1000, pp. 302-303.

Rahman M.K. and Ali M.S. (2012). Advanced Technologies and Strategies of *Pangasius* culture in Ponds. Fish Culture and Management Technology Guidelines. Ed: Director General, Bangladesh Fisheries Research Institute (BFRI), Mymenshingh. Pp 23-26 *(In Bengali)*.

Rahman M.M., Islam M.S., Halder G.C. and Tanaka M. (2005). Cage culture of sutchi catfish, *Pangasius sutchi* (Fowler 1937): effects of stocking density on growth, survival, and yield and farm profitability. Aquaculture Research, 1-7.

Sarker M.T. (2000). Pangus Chash Babastapana (Management of *Pangasius* Culture). A Fisheries leafleat in Bengali. Sheuli, Comilla Cantt., Comilla, Bangladesh.

United Nations Food and Agriculture Organization, 2010. Cultured Aquatic Species Information Programme. *Pangasius hypophthalmus*. FAO Fisheries and Aquaculture Department [online]. Rome. http://www.fao.org/fishery/culturedspecies/Pangasius_hypophthalmus/

Investigation 5

Alim, M. A., Wahab, M. A. and Milstein, A. 2004. Effects of adding different proportions of the small fish punti (Puntius sophore) and Mola (Amblypharyngodon Mola) to a polyculture of large carp. Aquaculture Research, 35:124-133.

Department of Fisheries, 2012. Fish Fortnight Compendium 2012. Department of Fisheries, Dhaka, Bangladesh.

Halver, J.E. 1984. Special methods in pond fish husbandry. AkademiaiNyomda, Budapest. 146 pp.

Johnson, S.K., Bueno, S.L.S. 2000. Health Management. pp. 239-258 *In*: Freshwater Prawn Culture: The farming of *Macrobrachium rosenbergii. Eds*. New, M.B., Valenti, W.C., Blackwell Science, U.K.

Kunda, M., Azim, M.E., Wahab, M.A., Roos, N., Thilsted, S.H., Dewan, S, 2008. The potential of mixed culture of freshwater prawn (*Macrobrachium rosenbergii*) and small indigenous *Mola* (*Amblypharyngodon Mola*) in rain-fed rotational rice-fish culture systems in Bangladesh. Aquaculture Res., 39, 506-517.

Lightfoot, C., Cruz, C.R.D., Carangal, V.R.1990. International Research Collaboration in rice-fish research. NAGA-The ICLARM Quarterly 13, 12-13.

Micronutrients Initiatives/UNICEF. 2004. Vitamin A and mineral deficiency: A global report. Ottawa, Canada.

Milstein, A., Kadir, A., Wahab, M.A. 2008. The effects of partially substituting Indian carps or adding silver carp on polycultures including small indigenous fish species (SIS).Aquaculture, 279, 92-98.

New, M.B., 2000.History and global status of freshwater prawn farming. pp. 1-11 *In*: Freshwater Prawn Culture: The farming of *Macrobrachium rosenbergii. Eds.* New, M.B., Valenti, W.C., Blackwell Science, Malden, MA,

Roos, N., Wahab, M.A., Mostafa, A.R.H, Thilsted, S.H. 2007. Linking human nutrition and fisheries: Incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. Food Nutrition Bull 28(2): S280-293.

Thilsted, S.H., Roos, N., Hassan, N., 1997. The role of small indigenous fish species in food and nutrition security in Bangladesh.NAGA-The ICLARM Quarterly 20, 82-84;102.
Wahab, M.A., Little, D., Verdegem, M., Kabir, S., Manjurul, K. 2001. Fish in the pond and crops in the dyke: an integrated farming system (in Bengali). Extension manual EU-funded Pond Live Project. BAU 8 p.
Wahab, M.A., Thilsted, S.H., Hoq, M.E. 2003. Small indigenous species of fish in Bangladesh: Culture potentials for improved nutrition and livelihood. Proceedings of ENRECA/DANIDA funded workshop held on 30-31 October 2002. Bangladesh Agricultural University (BAU), Mymensingh.166 pp.
Wahab, M.A., Kunda, M., Azim, M.E., Dewan, S., Thilsted, S.H. 2008. Evaluation of freshwater prawn-small fish culture concurrently with rice in Bangladesh. Aquaculture Res 39, 1524-1532.
Wahab, M.A., Kader, A., Milstein, A., Kunda, M. 2011.Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. Aquaculture 321, 289-297.
Wahab, M.A., Ahmed-Al-Nahid, S., Ahmed, N., Haque, M.M., Karim, M.M. 2012. Current status and prospect of farming of Giant River prawn *Macrobrachium rosenbergii* (De Man) in Bangladesh: a review. Aquaculture Res*,* 43, 970-983.
West, K.P. 2002. Extent of vitamin A deficiency among pre-school children and women at reproductive age. J Nutrition*,* 13 (2): 2857S-2866S.

Investigation 6

Belton, B., Karim, M., Thilsted, S., Murshed-E-Jahan, K., Collis, W., Phillips, M., 2011. Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center. November 2011.
Cuvin-Aralar, M.L.A., Aralar, E.V., Laron, M. and Rosario, W. 2007. Culture of *Macrobachium rosenbergii* (De Man 1879) in experimental cages in a freshwater eutrophic lake at different stocking densities. *Aquaculture Research*, 38 (3):288-294.
Department of Fisheries, 2012. Fish Fortnight Compendium 2012. Department of Fisheries, Dhaka, Bangladesh.
Egna, H.S. and C.E. Boyd (editors). 1997. Dynamics of Pond Aquaculture. CRC Press. Boca Raton, FL. 471 pp.
Jhinran, V.G., 1975. Fish and fisheries of India. Hindustan Pub. Corp. Delhi, India. 954 pp.
Kunda, M., Azim, M.E., Wahab, M.A., Roos, N., Thilsted, S.H., Dewan, S., 2008. The potential of mixed culture of freshwater prawn (*Macrobrachium rosenbergii*) and small indigenous mola (*Amblypharyngodon mola*) in rain-fed rotational rice-fish culture systems in Bangladesh. *Aquaculture Research,* 39, 506-517.
Micronutrients Initiatives/UNICEF. 2004. Vitamin A and mineral deficiency: A global report. Ottawa, Canada.
Milstein, A., Kadir, A., Wahab, M.A., 2008. The effects of partially substituting Indian carps or adding silver carp on polyculture including small indigenous fish species (SIS). *Aquaculture,* 279, 92-98.
Roos, N., Wahab, M.A., Mostafa, A.R.H, Thilsted, S.H., 2007. Linking human nutrition and fisheries: Incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. *Food Nutrition Bull,* 28(2), S280-293.
Wahab, M.A., Thilsted, S.H., Hoq, M.E., 2003. Small indigenous species of fish in Bangladesh: Culture potentials for improved nutrition and livelihood. Proceedings of ENRECA/DANIDA funded workshop held on 30-31 October 2002. Bangladesh Agricultural University (BAU), Mymensingh. 166 pp.
Wahab, M.A., Kunda, M., Azim, M.E., Dewan, S., Thilsted, S.H., 2008. Evaluation of freshwater prawn-small fish culture concurrently with rice in Bangladesh. *Aquaculture Research,* 39, 1524-1532.

Wahab, M.A., Kader, A., Milstein, A., Kunda, M., 2011. Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. *Aquaculture,* 321, 289-297.

Investigation 7

Ahmed, N., 2007. Development of Tilapia Marketing Systems in Bangladesh: Potential for Food Supply. National Food Policy Capacity Strengthening Programme. Final Report. Bangladesh.

Ali, M.Y., Kamal, D., Hossain, S.M.M., Azam, M.A., Sabbir, W., Mushida, A., Ahmed, B. and Azam, K. 2004. Biological studies of the mud crab, *Scylla serrata* (Forskål) of the Sundarbans mangrove ecosystem in Khulna region of Bangladesh. Pakistan J. Biol. Sci., 1967 (11): 1981-87.

Anon, 2008. Promoting Sustainable Coastal Aquaculture in Bangladesh (ProsCAB). Final Report of DFID funded Research Into Use (RIU) program. Bangladesh Fisheries Research Forum (BFRF). 91 pp.

Azam, K., D. Kamal and M. Mostafa. 1998. Status and potential of mud crab (*Scylla serrata*) in Bangladesh. *In*: Rahman, M.A. M.S Shah, M.G. Murtaza, and M.A. Matin (Eds.). Proc. Nat. Sem. Integr. Manage. Ganges Floodplains and Sundarbans Ecosystem, July 16-18, 1994. Khulna University, Bangladesh Agricultural Research Council and Department of Agricultural Extension. Khulna University, Bangladesh, pp. 150-160.

Begum, M., Shah, M.M.R., Al Mamun, A., Alam, M. J. 2009. Comparative study of mud crab (*Scylla serrata*) fattening practices between two different systems in Bangladesh. J. Bangladesh Agril. Univ. 7(1): 151–156.

Belton, B., Karim, Thilstead, S., Murshed-E-Jahan, K., Collis, W., Phillips, M. 2011. Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center. November 2011.

Cooper, M.C., Lambert, D.M. and Pagh J.D. 1997. Supply Chain Management: More than a New Name in Logistics. The International Journal of Logistics Management. 8 (1).Department of Agriculture (DA), Region VI. 1988. Fattening mud crabs *Scylla serrata* in bamboo cages. Fish Extension Rep., Dept. of Agriculture, BFAR, Philippines. Development, dry weight and chemical composition of larvae of the mud crab *Scylla paramamosain*. Pages 159-166 in Keenan, C.P. and Blackshaw, A. W. (Eds.), Mud crab aquaculture and biology: Proceedings of an international scientific forum April 21-24. 1997. Australian Centre for International Agricultural Research, Canberra.

Felix, S, M. Gazendran and S. Subramaniam. 1995. Aquaculture of Mud Crab. *Seafood Export J*. 26(6) 5-6.

Ferdoushi, Z. and Z Xiang-Guo. 2010b. Role of Women in Mud Crab (*Scylla sp*) Fattening in Southwest Part of Bangladesh. Marine Resource and Aquaculture 1(1):5-13.

Hussain, M.G. 2009. A future for the tilapia in Bangladesh. AQUA Culture AsiaPacific Magazine July-August 2009, p. 38-40.

Jamandre, W.E. and L.U. Hatch. 2010. Improving supply chain opportunities for tilapia in the Philippines. USAID CRSP Final Technical Report.

Khan, M.G. and Alam, M.F. 1991. The mud crab (*Scylla serrata*) fishery and its bio-economics in Bangladesh. BOBP/REP 51: 29-40.

Keenan, C.P. and Blackshaw, A. W. (Eds.), Mud crab Aquaculture and Biology. Proceedings of an International Scientific Forum held in Darwin, Australia, 21-24 April 1997. ACIAR proceedings No. 78. Watson Ferguson and Company, Brisbane, Australia.

Kuntiyo, A. 1992. Fattening of mud crab, *Scylla serrata* Forskal, in net cages installed in the drain canal of intensive prawn ponds fed with trash fish and prawn pellate. MS Thesis. University of the Philippines in the Visayas. pp. 60.

Magnani, R. 1999. Sampling Guide. Washington, D.C.: FHI 360/ Food and Nutrition Technical Assistance III Project (FANTA). 11 p.

Popma, T., Masser, M. 1999. Tilapia: life history and biology. Southeastern Regional Aquaculture Center (SRAC) Publication No. 283.

Ramasamy, C. 2007. Supply Chain Management in Agriculture: Trends, Status and Initiatives taken in Tamil Nadu Agricultural University. Tamil Nadu Agricultural University.

Shelley, C., Lovatelli, A. 2011. Mud crab aquaculture: a practical manual. FAO Fisheries and Aquaculture Technical Paper No. 567. United Nations Food and Agricultural Organization, Rome, Italy. 78 p.

Sivasubramain, K and Angel, C.A. 1992. A review of the culture, marketing and resources of the mud crab. In: The mud crab (ed. C.A. Angel). Bay of Bengal Program, Madras. India. pp. 5-12.

Swindale, A., Bilinsky, P. 2006.Household Dietary Diversity Score (HDDS) for measurement of household food access: Indicator Guide (v.2). Washington, D.C.: FHI 360/ Food and Nutrition Technical Assistance III Project (FANTA).

Williamson, O. 1979. Transaction-cost economics: the governance contractual relations. J. Law and Econ. 22: 233-261.

World Food Programme, 2011. A Rapid Food Security Assessment at Satkhira in the Context of Recent Flood and Water Logging. August 2011. Available online at http://documents.wfp.org /stellent/ groups/public/documents/ena/wfp240049.pdf.

Zafar, M.A. and Ahsan, M.N. 2006. Marketing and Value Chain Analysis of Mud Crab (*Scylla sp.*) in the Coastal Communities of Bangladesh. Project Report on Marketing and value chain analysis of Mud Crab. Bangladesh Fisheries Research Forum (BFRF), Dhaka. 53 pp.

Zafar, M. and Siddiqui, M.Z.H. 2000. Occurrence and abundance of four Brachyuran crabs in the Chakaraia Sundarban of Bangladesh. The Chittagong Univ. Jour. Sci., 24(2): 105-110.

Literature Cited, University of Connecticut at Avery Point

Investigation 1
No literature cited.

Investigation 2

Duc, P.M., T.N. Tuan, and TTT Hien, 2012. An investigation on pathogen infection to cultured snakehead (Channa striata) in An Giang and Dong Thap province. Journal of Science, Can Tho University. 21b: 124-132.

Duc, P.M., T.N. Tuan and K. Hatai, In press. Pathogenicity of *Aeromonas hydrophila* to snakehead (*Channa striata*) fingerlings. Fisheries pathothology, Japan.

Le Xuan Sinh and Do Minh Chung 2010. Current situation of and challenges for snakehead *(channa micropeltes* and *channa striatus)* farming in the Mekong Delta, Vietnam. Scientific and Technology Journal of Agriculture and Rural Development, No.10/2010, pp.56-63.

AquaFish-CRSP project (2010). Value chain of cultured snakehead fish in the Lower Mekong Basin of Vietnam.

AquaFish-CRSP project (2010). Alternative Feeds for Freshwater Aquaculture Species

Investigation 3

Allison EH, Perry AL, Badjeck MC, Neil Adger W, Brown K., Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries, 10(2):173-196.

Arockiaraj, A.J., M. Muruganandam, K. Marimuthu and M.A. Haniffa. 1999. Utilization of carbohydrates as a dietary energy source by striped murrel, *Channa striatus* (Bloch) fingerlings. *Acta Zool. Taiwan* 10: 103-111.

FiA (2009). Fishing for the future: A strategic planning framework (SPF) for fisheries: 2009-2018 (draft version 7b, 30th April, 2009).

Halls, A.S., Chheng, P., So, N.; Thuok, N.(2012). Food and Nutrition Security Vulnerability to Mainstream Hydropower Dam Development in Cambodia: Impacts of mainstream dams on fish yield and consumption in Cambodia. Inland Fisheries Research and Development Institute (IFReDI), Fisheries Administration, March 2012, 90 pp.

Phillips MJ (2002). Freshwater aquaculture in the Lower Mekong Basin. Technical Paper No. 7, Mekong River Commission, Phnom Penh. 62 pp. ISSN: 1683-1486.

Samantaray, K. and S.S. Mohanty. 1997. Interactions of dietary levels of protein and energy on fingerling snakehead, Channa striata. Aquaculture 156: 245-253.

So N (2009). Snakehead culture in the Mekong Delta of Vietnam. Inland Fisheries Research and Development Institute, Phnom Penh.

So N and Haing L (2006). A Review of Freshwater Fish Seed Resources in Cambodia. A consultancy report for FAO and NACA. Inland Fisheries Research and Development Institute, Department of Fisheries, Phnom Penh, Cambodia.

So N, Eng Tong, Souen Norng and Kent Hortle (2005). Use of freshwater low value fish for aquaculture development in the Cambodia's Mekong basin. Consultancy report for Mekong River Commission – Assessment of Mekong Capture Fisheries Project. Inland Fisheries Research and Development Institute, Department of Fisheries, Phnom Penh, Cambodia.

So N, Lenh SV, Kura Y (2007). Study of the catch and market chain of low value fish along Tonle Sap River, Cambodia- Implications for management of their fisheries (A preliminary study). Inland Fisheries Research and Development Institute, Phnom Penh.

So N, Sam Narith, Dr. Bui Minh Tam, Dr. Tran Thi Thanh Hien, and P. Robert (2011). Sustainable snakehead aquaculture development in the Lower Mekong River Basin of Cambodia and Vietnam- Part 1: Breeding and Weaning of striped snakehead (Channa striata) in Cambodia.

Inland Fisheries Research and Development Institute (IFReDI), Fisheries Administration, September 2011, 57 pp.
WorldFish Center. 2007. Fisheries and aquaculture can provide solutions to cope with climate change. Issues brief. WorldFish Center, Penang, Malaysia.

Investigation 4

Beveridge, M. 1993. Cage and pen fish farming: carrying capacity models and environmental impact. FAO Fisheries Technical Paper 255.
Byron, C., D. Bengtson, B. Costa-Pierce and J. Calanni. 2011. Integrating science into management: ecological carrying capacity of bivalve shellfish aquaculture. Marine Policy 35: 363-370.
Byron, C., J. Link, B. Costa-Pierce and D. Bengtson. 2011. Modeling ecological carrying capacity of shellfish aquaculture in highly flushed temperate lagoons. Aquaculture 314: 87-99.
Byron, C., J. Link, B. Costa-Pierce and D. Bengtson. 2011.Calculating carrying capacity of shellfish aquaculture using mass-balance modeling: Narragansett Bay, Rhode Island. Ecological Modeling 222:1743-1755.
Duarte, P., R. Meneses, A. J. S. Hawkins, M. Zhu, J. Fang, J. Grant. 2003. Mathematical modeling to assess the carrying capacity for multi-species culture within coastal waters. Ecological Modelling 168:109-143.
Mckindsey, C. W., H. Thetmeyer, T. Landry, W. Silvert. 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261(2): 451-462.
Stigebrandt, A. 2011, Carrying capacity: general principles of model construction. Aquaculture Research. 42: 41-50
Soto, D., J., Aguilar-Manjarrez, C. Brugère, D. Angel, C. Bailey, K. Black, P. Edwards, B. Costa-Pierce, T. Chopin, S. Deudero, S. Freeman, J. Hambrey, N. Hishamunda, D. Knowler, W. Silvert, N. Marba, S. Mathe, R. Norambuena, F. Simard, P. Tett, M. Troell, A. Wainberg (2008). Applying an ecosystem-based approach to aquaculture: principles, scales and some management measures. In D. Soto, J. Aguilar-Manjarrez and N. Hishamunda (eds). Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceedings. No. 14. Rome, FAO. pp. 15–35.

Investigation 5

Cambodia Human Development Report, The Future for Rural Livelihoods in the face of Climate Change, 2011
Cochrane, K.; De Young, C.; Soto, D.; Bahri, T. (eds).Climate change implications for fisheries and aquaculture: overview of current scientific knowledge.
FAO Fisheries and Aquaculture Technical Paper.No. 530. Rome, FAO. 2009. 212p.
Halls, A.S., Chheng, P., So, N.; Thuok, N. 2012. Food and Nutrition Security Vulnerability to Mainstream Hydropower Dam Development in Cambodia: Impacts of mainstream dams on fish yield and consumption in Cambodia. Inland Fisheries Research and Development Institute (IFReDI), Fisheries Administration.90 pp.
Lisa Futtrup Borg. 2011. Climate Change and Human Security in Cambodia. CICP working paper 46. Cambodian Institute for Cooperation and Peace, Phnom Penh
Marko Keskinen, Matti Kummu, Mira Kakonen. 2012. Mekong at the Crossroads: Next Steps for Impact Assessment of Large Dams. AMBIO 41:319–324.
Mekong River Commission. 2009. Hydropower Sector Review for the Joint Basin Planning Process.
Orr, S. et al. 2012. Dams on the Mekong River: Lost fish protein and the implications for land and water resources. Global Environ. Change. http://dx.doi.org/10.1016/j.gloenvcha.2012.06.002
RAP Publication 2011/16, 41 pp.

Sriskanthan, G. andFunge-Smith, S. J. (2011).The potential impact of climate change on fisheries and aquaculture in the Asian region.FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Investigation 6

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi. 2007. "Assessment of adaptationpractices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II." Fourth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 717–743. M.L. Parry, O.F. Canziani, J.P.Palutikof, P.J. van der Linden, and C.E. Hanson, eds. Cambridge, UK: Cambridge University Press.

Smit, B., and J. Wandel. 2006. "Adaptation, adaptive capacity and vulnerability." Global Environmental Change 16(3): 282–292.

Smit, B., I. Burton, R.J.T. Klein, and R. Street. 1999. "The science of adaptation: A framework for assessment." Mitigation and AdaptationStrategies for Global Change 4(3): 199–213.

Literature Cited, Purdue University

Adeparusi, E. O., and J. O. Agbede. 2005. Evaluation of Leucaena and Gliricidia leaf protein concentrate as supplements to bambara groundnut Vignas subterranean in the diet of Oreochromis niloticus. Aquaculture Nutrition 12:335-342.

Al-Asgah, N.A., and A. Ali. 1997. Growth performance and body composition of Oreochromis niloticus reared at different water temperatures. Annales De Zootechnie 46:331-338.

Antoine F. R., C. I. Wei , R. C. Littell , and M. R. Marshall (1999). HPLC Method for Analysis of Free Amino Acids in Fish Using o-Phthaldialdehyde Precolumn Derivatization. Journal of Agricultural and Food Chemistry 47 (12): 5100–5107.

AOAC (1990). Official Methods of Analysis of the Association of Analytical Chemists. 15th ed. A.O.A.C. Washington, D.C., USA.

AOAC (Association of Official Analytical Chemists). 1995. Official methods of analysis. Arlington, Virginia.

AOAC (Association of Official Analytical Chemists). 2005. Official methods of analysis. Arlington, Virginia.

Arole, R. S. (1999). Inter-Sectoral Co-ordination for Primary Health Care. Jamkhed: Comprehensive Rural Health Project (CRHP).

Arterburn, L.M., E.B. Hall, and H. Oken. 2006. Distribution, interconversion, and dose response of n-3 fatty acids in humans. American Journal of Clinical Nutrition 83(Supplement):1467S-1476S.

Azaza, M.S., M.N. Dhraief, et al. 2008. Effects of water temperature on growth and sex ratio of juvenile Nile tilapia Oreochromis niloticus (Linnaeus) reared in geothermal waters in southern Tunisia. Journal of Thermal Biology 33: 98-105.

Baras, E., B. Jacobs, et al. 2001. Effect of water temperature on survival, growth and phenotypic sex of mixed (XX-XY) progenies of Nile tilapia Oreochromis niloticus. Aquaculture 192:187-199.

Béné, C. and Heck, S. (2005). “Fish and food security in Africa.” NAGA, World fish Centre Quarterly report, 28: 8-13.

Berg, M., Boomsma, M., Cucco, I., Janssen, N. (2008). Making Value Chain Work better for the poor. A toolbook for practitionners of value Chain Analysis. DFID, UK. Version 2.

Bhujel, R.C., Shrestha, K., Pant, J and Buranrom, S. (2008). “Ethnic women in aquaculture in Nepal”. Development, 51: 259-264.

Brummett R. E., Lazard E. and Moehl J. (2008). African aquaculture: Realizing the potential. Food Policy 33: 371-385

Bueno, P.B. (2009). “Indicators of sustainable small scale aquaculture development” In: Bondad-Reantaso M.G. and Prein, M. (eds). Measuring the contribution of small scale aquaculture: an assessment. FAO Fisheries and Aquaculture Technical Paper, No. 534, pp 145-160.

Charo-Karisa, H., H. Komen, et al. 2006. Genetic and environmental factors affecting growth of Nile tilapia (Oreochromis niloticus) juveniles: Modelling spatial correlations between hapas. Aquaculture 255:586-596.

Chirwa, E.W. and Ngalawa, H.P. (2008). Determinants of Child Nutrition in Malawi, South African Journal of Economics 76, 628-640.

Crawford, B.C., M.D. Herrera, N. Hernandez, C. Rivas-LeClair, N. Jiddawi, M. Semba, M.C. Haws. 2010. Small scale fisheries management: lessons from cockle harvesters in Nicaragua and Tanzania. Coastal Management Journal. 38:195-215.

De Silva, S.S. and Davy, E.B. (2010). “Aquaculture success in Asia: Contributing to sustained development and poverty alleviation” In: De Silva, S. and Davy, F.B (eds) Success stories in Asian aquaculture. Springer, International Development Research Centre pp 1-14.

Dehejia, R., and S. Wahba. 2002. “Propensity-score Matching Methods for Nonexperimental Causal Studies”. The Review of Economic and Statistics, 84(1): 151-161.

Dewedar, R. 2013. Fast-growing fish variety could benefit Egypt and West Africa. The Science and Development Network, http://www.scidev.net/en/agriculture-and-

environment/fisheries/news/fast-growing-fish-variety-could-benefit-egypt-and-west-africa-.html (Retrieved 4/24/2013).
Drummond, C. D., L. D. Solis Murgas, et al. 2009. Growth and survival of tilapia Oreochromis niloticus (Linnaeus, 1758) submitted to different temperatures during the process of sex reversal. Ciencia E Agrotecnologia 33:895-902.
Ellis, S. and M. Haws. 1999. Producing pearls using the black-lip pearl oyster (Pinctada margaritifera). Center for Tropical and Subtropical Aquaculture (CTSA). Honolulu, HI.
El-Saidy D.M.S.D. and Gaber M.M.A. (2002). Complete Replacement of Fishmeal by Soybean Meal with Dietary L-Lysine Supplementation for Nile Tilapia Oreochromis niloticus (L.) Fingerlings. Journal of the World Aquaculture Society 33 (3):297-306.
El-Sayed, A.-F. M., and M. Kawanna. 2008. Optimum water temperature boosts the growth performance of Nile tilapia Oreochromis niloticus fry reared in a recycling system. Aquaculture Research 39:670-672.
El-Sayed, A.F.M. (1999). Alternative dietary protein sources for farmed tilapia, Oreochromis spp. Aquaculture 179 (1-4):149-168.
El-Sayed, A.-F.M. 2006. Tilapia culture in salt water: environmental requirements, nutritional implications, and economic potentials. En: Editors Suarez, E.L.C. et al. Advances en Nutricion Acuicola VIII. Symposium Internacional de Nutricion Acuicola. 15-17 November. Universidad Autonoma de Nuevo Leon, Monterey, Nuevo Leon, Mexico.
El-Zaeem, S. Y., M. M. M. Ahmed, et al. 2011. Production of salinity tolerant Nile tilapia, Oreochromis niloticus through traditional and modern breeding methods: II. Application of genetically modified breeding by introducing foreign DNA into fish gonads. African Journal of Biotechnology 10:684-695.
FAO (2007). The State of Fisheries and Aquaculture - 2006. Rome, Italy: Food and Agriculture Organisation of the United Nations.
FAO (2012). The State of World Fisheries and Aquaculture 2012. Rome, Italy: Food and Agriculture Organisation of the United Nations.
FAO, 2012. The State of World Fisheries and Aquaculture 2012. World Review of Fisheries and Aquaculture (Part I). FAO Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Rome, 2012
Ficke, A.D., C.A. Myrick, et al. 2007. Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries 17:581-613.
Folch, J., M. Lees, and G. H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry 226:497-509.
Galiani, S., P. Gertler, and E. Schargrodsky. 2005. “Water for Life: The Impact of the Privatization of Water Services on Child Mortality”. Journal of Political Economy, 113(1): 83-120.
Handisyde, N.T., L.G. Ross, et al. 2005. The effects of climate change on world aquaculture: A global perspective. DFID, London, UK.
Hardy, R.W. and F. T. Barrows. 2002. Diet formulation and manufacture. Pages 505-600 in J.E. Halver and R.W. Hardy, editors. Fish nutrition, third edition. Academic Press, New York.
Haws, M.C., B. Crawford, S.C. Ellis, N. Jiddawi, A. Mmochi, E. Gaxiola-Camacho, G. Rodriguez-Dominguez, G. Rodriguez, J. Francis, C. Rivas-LeClair, A. Saborio-Coze, N. Hernandez, E. Sandoval, K. Dabrowski, M.C. Portella and M. Jaroszewska. 2010. Aquaculture research and development as an entry-point and contributor to natural resources and coastal management. Coastal Management Journal: 38: 238-261.
Hecht, T. 2007. Review of feeds and fertilizers for sustainable aquaculture development in sub-Saharan Africa. Pages 77-109 in M.R. Hasan., T. Hecht, S.S. De Silva, and A.G.J. Tacon, editors. Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO, Rome.
Hempel, E. (2010). Value Chain Analysis in the Fisheries sector in Africa. http://www.fao.org/fileadmin/user_upload/fisheries/docs/Value_Chain_Analysis_Report_FINAL_hempel.doc. Downloaded on 10th April 2012.

HKI (Helen Keller International)/Asia-Pacific. 2001. Homestead Food Production: A Strategy to Combat Malnutrition and Poverty. Jakarta, Indonesia.
Horrocks, L.A., and Y.K. Yeo. 1999. Health benefits of docosahexaenoic acid (DHA). Pharmacological Research 40:211-225.
Hussain M.G., Kohinoor A.H.M., Islam M.S., Mahata S.C., Ali M.Z., Tanu M.B., Hossain M.A. and Mazid M.A. (2000). Genetic evaluation of GIFT and existing strains of Nile Tilapia, Oreochromis niloticus L.,under on-station and on-farm conditions in Bangladesh. Asian Fisheries Science 13: 117-126
InfoFish. 2008. SMS-Based Fish Marketing Information System Launched. InfoFish International, Vol 5, pp. 52.
InfoFish. 2010. Workshop on Fish Marketing Information System in Indonesia. InfoFish - Fishing Technology Digest for Asia-Pacific, Issue 70, April-June 2010 pp. 6.
Innis, S. M. 2007. Dietary (n-3) fatty acids and brain development. Journal of Nutrition 137:855-859.
Jahan, K. M-e., Ahmed, M. and Beltom, B. (2010). "The impacts of aquaculture development on food security: lessons from Bangladesh". Aquaculture Research, 41:481-495.
Jalan, J., and M. Ravallion. 2003. "Estimating the Benefit Incidence of an Antipoverty Program by Propensity-Score Matching". Journal of Business and Economic Statistics, 21(1): 19-30.
Jauncey K. (1998). Tilapia feeds and feeding. Scotland: Pisces Press Limited.
Jiddawi, N. 2008. Pearl farming in Zanzibar. SPC Pearl Farming Bulletin. May 2008. Secretariat of the Pacific Community. Accessed at: http://www.spc.int/DigitalLibrary/Doc/FAME/InfoBull/POIB/18/POIB18_18_Jiddawy.pdf
Jiddawi, N.S. 2012. The artisanal fisheries and other marine resources in Chwaka Bay. In: People, Nature and Research in Chwaka Bay, Zanzibar, Tanzania. de La Torre-Castro and Lyimo, T.J. (eds.). page 213-212. WIOMSA. Zanzibar Town, Tanzania.
Kamal, H.A.M.M., and G.C. Mair. 2005. Salinity tolerance in superior genotypes of tilapia, Oreochromis niloticus, Oreochromis mossambicus and their hybrids. Aquaculture 247:189-201.
Karapanagiotidis, I.T., Bell, M.V., Little, D.C., Yakupitiyage, A., 2007. Replacement of dietary fish oils by alpha-linolenic acid-rich oils lowers omega-3 content in tilapia flesh. Lipids 42:547–559.
Kasiga, T. 2012. Evaluation of Moringa oleifera and Leucaena leucocephala leaf meals as alternative protein sources in diets of Nile tilapia. M.S. Thesis. University of Arkansas at Pine Bluff.
Kenya Marine and Fisheries Research Institute – KMFRI. 2010. Enhanced Fish Market Information System. Aquanews - KMFRI newsletter, Vol 1, Issue 1. April 2010, pp 7.
Kolding, J., L. Haug, et al. 2008. Effect of ambient oxygen on growth and reproduction in Nile tilapia Oreochromis niloticus. Canadian Journal of Fisheries and Aquatic Sciences 65:1413-1424.
Kumar, K., and J. Eriksson. 2011. A meta-evaluation of foreign assistance evaluations. Office of the Director of US Foreign Assistance, Department of State, Washington, DC.
Lazard, J., Baruthio, A., Mathe, S., Rey-Valette, H., Chia, E., Clement, O., Aubin, J., Morissens, P., Mikolasek, O., Legendre, M., Levang, P., Blancheton, J. and Rene, F. (2010). "Aquaculture system diversity and sustainable development: fish farms and their representation". Aquatic Living Resources, 23: 187-198.
Lee, W.-J., and T. D. Kocher. 1996. Microsatellite DNA markers for genetic mapping in the tilapia, Oreochromis niloticus. Journal of Fish Biology 49: 169–171.
Leung, T.L.F., and A.E. Bates. 2013. More rapid and severe disease outbreaks for aquaculture at the tropics: implications for food security. Journal of Applied Ecology 50:215-222.
Likongwe, J. S., T. D. Stecko, et al. 1996. Combined effects of water temperature and salinity on growth and feed utilization of juvenile Nile tilapia Oreochromis niloticus (Linneaus). Aquaculture 146: 37-46.
Machena C. and Moehl J. (2000). African Aquaculture: A Regional Summary with Emphasis on Sub-Saharan Africa . In: Subasinghe, R.P., Bueno, P., Phillips, M.J. , Hough, C., McGladdery, S.E. and Arthur, J.R., (Eds.). Technical Proceedings of the Conference on Aquaculture in the Third Millennium, 20-25 February2000, Bangkok, Thailand, Bangkok and Rome. NACA and FAO

Madalla N.A. (2008). Novel feed ingredients for Nile Tilapia (Oreochromis niloticus L). PhD Thesis, University of Stirling, UK.
Madalla, N. 2008. Novel feed ingredients for Nile tilapia Oreochromis niloticus L. Doctoral dissertation, Institute of Aquaculture, University of Stirling, Scotland.
Madise, N.J., Matthews, Z. and Margetts, B. (1999). Heterogeneity of child nutritional status between households: A comparison of six sub-saharan African countries, Population Studies 53, 331-343.
Mbwana M. K. (2010). Evaluation of Moringa oleifera and Leucaena Leucocephala as protein sources in Tilapia diets. MSc. Dissertation, Sokoine University of Agriculture, Tanzania.
Mohanta KN., Subramanian S. and Korikanthimath V.S. (2013). Evaluation of Different Animal Protein Sources in Formulating the Diets for Blue Gourami, Trichogaster Trichopterus Fingerlings. Journal of Aquaculture Research and Development 4:164 doi:10.4172/2155-9546.1000164
Morrison, W. R., and L. M. Smith. 1964. Preparation of fatty acid methyl esters and dimethyl esters and dimethylacetals from lipids with boron fluoride-methanol. Journal of Lipid Research 5:600-608.
Msuya, F.E., M.S. Shalli, K. Sullivan, B. Crawford, J. Tobey and A.J. Mmochi. 2007. A Comparative Economic Analysis of Two Seaweed Farming Methods in Tanzania. Coastal Resources Center, University of Rhode Island for USAID. Accessed at: http://pdf.usaid.gov/pdf_docs/PNADK663.pdf
Nelson, E., and P. Wallace. 1998. Report on a survey of agroindustrial byproducts in Northern Ghana. Aquatic Research Institute Technical Report (Available from WRI, Ghana).
Neves P. R., Ribeiro R. P., Vargas L., Natali M.R.M., Maehana K. R. and Marengoni N.G. (2008). Evaluation of the Performance of Two Strains of Nile Tilapia (Oreochromis Niloticus) In Mixed Raising Systems. Brazilian Archives of Biology and Technology 51 (3): 531 – 538
NRC (Nutrient Requirements of Fish). 2011. National Research Council. Washington D.C.: National Academy Press.
Omoyinmi G.A.K. and Olaoye O.J. (2012). Growth Performance of Nile Tilapia-Oreochromis niloticus Fed Diets Containing Different Sources of Animal Protein. Libyan Agriculture Research Center Journal International 3 (1): 18-23, 2012
Pandit, N.P., and M. Nakamura. 2010. Effect of high temperature on survival, growth, and feed conversion ratio of Nile tilapia, Oreochromis niloticus. Our Nature 8:219-224.
Papoutsoglou, S. E. and G. Tziha. 1996. Blue tilapia Oreochromis aureus growth rate in relation to dissolved oxygen concentration under recirculated water conditions. Aquacultural Engineering 15:181-192.
Paugy, D., C. Leveque, and G. G. Teugels. 2003. The fresh and brackish water fishes of West Africa, Volume II. IRD Editions, Publications Scientifiques du Museum, MRAC., Belgium.
Place, A.R. 1983. Isozymes. Current Topics in Biological and Medical Research 10(Genetics and Evolution):147-170.
Quinn, V., Chiligo, M. and Gittinger, J.P. (1990). Malnutrition, household income and food security in rural Malawi, Health Policy and Planning 5, 139-148.
Rengmark, A. H., A. Slettan, et al. 2007. Identification and mapping of genes associated with salt tolerance in tilapia. Journal of Fish Biology 71:409-422.
Rognon, X., and R. Guyomard. 1997. Mitochondrial DNA differentiation among East and West African Nile tilapia populations. Journal of Fish Biology 51:204-207.
Sahn, D.E. and Alderman, H. (1997). On the Determinants of Nutrition in Mozambique: The Importance of Age-Specific Effects, World Development 25, 577-588.
Satia (2011). Regional review on status and trends in aquaculture development in Sub-Saharan Africa – 2010. FAO, Rome 214p.
Schofield, P. J., M. S. Peterson, et al. 2011. Survival, growth and reproduction of non-indigenous Nile tilapia, Oreochromis niloticus (Linnaeus 1758). I. Physiological capabilities in various temperatures and salinities. Marine and Freshwater Research 62:439-449.

Shigulu H. (2012). Effect of substituting Sunflower seed meal and soybean meal with Moringa oleifera leaf meal in Nile Tilapia (Oreochromis niloticus) diet. MSc. Dissertation, Sokoine University of Agriculture, Tanzania.
Siekmann, J., and S.L. Huffman. 2011. Fat in the critical 1000 days: ensuring adequacy of essential dietary fats for mothers and young children in low and middle income countries. Meeting Report, April 7, 2011, Washington D.C. Global Alliance for Improved Nutrition. http://www.gainhealth.org.
Simopoulos, A. 2008. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Experimental Biology and Medicine 233:674-688.
Stanturf, J. A., M. L. Warren, Jr., S. Charnley, S. C. Polasky, S. L. Goodrick, F. Armah, and Y. A. Nyako. 2011. Ghana climate change vulnerability and adaptation assessment. USAID, Washington, DC.
Teng J.I. and N.M. Made Gowda (1993). Analysis of n-3 fatty acids in fish oils by high-performance liquid chromatography. Chromatographia 35 (9 – 12): 627 – 630.
Tharakan, C.T. and Suchindran, C.M. (1999). Determinants of child malnutrition-An intervention model for Botswana, Nutrition Research 19, 843-860.
Tocher, D. R. 2003. Metabolism and functions of lipids and fatty acids in teleost fish. Reviews in Fisheries Science 11:107-184.
Tran-Duy, A., J. W. Schrama, et al. 2008. Effects of oxygen concentration and body weight on maximum feed intake, growth and hematological parameters of Nile tilapia, Oreochromis niloticus. Aquaculture 275:152-162.
Trujillo, A., J. Portillo, and J. Vernon. 2005. "The Impact of Subsidized Health Insurance for the Poor: Evaluating the Colombian Experience Using Propensity-score matching". International Journal of Health Care Finance and Economics, 5(3): 211-239.
Trushenski, J., and R. Lochmann. 2009. Potential, implications and solutions regarding the use of rendered animal fats in aquafeeds. American Journal of Animal and Veterinary Sciences 4(4):108-128.
Trushenski, J.T., J. Boesenberg, and C.C. Kohler. 2009. Influence of grow-out feed fatty acid composition on finishing success in Nile tilapia. North American Journal of Aquaculture 71:242-251.
Turchini, G.M., W-K. Ng, and D.R. Tocher. 2011. Fish oil replacement and alternative lipid sources in aquaculture feeds. CRC Press, Boca Raton, Florida.
URT. (1997). National Fisheries sector policy and strategy statement. Ministry of Natural resources and Tourism, Dar es Salaam, Tanzania.
URT. (1997). National Fisheries sector policy and strategy statement. Ministry of Natural resources and Tourism, Dar es Salaam, Tanzania.
von Braun, J. (2007). The World Food Situation - New Driving Forces and Required Actions. Washington, D.C.: International Food Policy Research Institute.
Weaver, K.L., P. Ivester, J.A. Chilton, M.D. Wilson, P. Pandey, and F.H. Chilton. 2008. The content of favorable and unfavorable polyunsaturated fatty acids found in commonly eaten fish. Journal of the American Dietetic Association 108:1178-1185.
Williams, L., and A. Rota. 2010. Impact of climate change on fisheries and aquaculture in the developing world and opportunities for adaptation. International Fund for Agricultural Development, Rome, Italy.
Xie, S., K. Zheng, et al. 2011. Effect of water temperature on energy budget of Nile tilapia, Oreochromis niloticus. Aquaculture Nutrition 17:E683-E690.
Yan, B. A. and Z. H. Wang (2010). Growth, salinity tolerance and microsatellite analysis of the F-2 reciprocal hybrids of Oreochromis niloticus x Sarotherodon galilaeus at different salinities. Aquaculture Research 41:e336-e344.
Zambrano, L., E. Martinez-Meyer, et al. 2006. Invasive potential of common carp Cyprinus carpio and Nile tilapia Oreochromis niloticus in American freshwater systems. Canadian Journal of Fisheries and Aquatic Sciences 63:1903-1910.

ZPRP. 2002. Revolutionary Government of Zanzibar's Zanzibar Poverty Reduction Plan. Accessed at: http://www.hakikazi.org/zwp/

Literature Cited, University of Michigan

Aiga, H., S. Matsuoka, C. Kuriowa, and S. Yamamoto. 2009. Malnutrition among children in rural Malawian fish-farming households. Transactions of the Royal Society of Tropical Medicine and Hygiene 103:827-833.

Alikunhi, K.H. 1957. Fish Culture in India. Farm Bulletin No. 20. Indian Council of Agricultural Research, New Delhi, pp. 144.

Azadi, M.A., and M.S. Siddique. 1986. Fecundity of the catfish, *Heteropneustes fossilis* (Bloch). Bangladesh Journal of Zoology 14:33-39.

Azim, M.E., M.M. Rahaman, M.A. Wahab, T. Asaeda, D.C. Little, and M.C.J. Verdegem. 2004. Periphyton-based pond polyculture system: a bioeconomic comparison of on-farm and on-station trials. Aquaculture 242:381–396.

Azim, M.E., M.C.J. Verdegem, H. Khatoon, M.A Wahab, A.A van Dam, and M.C.M. Beveridge. 2002. A comparison of fertilization, feeding and three periphyton substrates for increasing fish production in freshwater pond aquaculture in Bangladesh. Aquaculture 212:227-243.

Azim, M.E., M.A. Wahab, A.A., van Dam, M.C.M. Beveridge, and M.C.J. Verdegem. 2001. The potential of periphyton-based culture of two Indian major carps, rohu *Labeo rohita* (Hamilton) and gonia *Labeo gonius* (Linnaeus). Aquaculture Research 32:209-216.

Bhujel, R.C., M.K. Shrestha, J. Pant, and S. Buranrom. 2008. Ethnic women in aquaculture in Nepal. Development 51:259-264.

Bista, J.D., T.B. Gurung, S.K. Wagle, and A.K. Rai. 2008. Present status and prospects of sahar (*Tor putitora*) fisheries in Nepal. Journal of the Institute of Agriculture and Animal Sciences 29:1-11.

Bista, J., B.R. Pradhan, A.K. Rai, R.K. Shrestha, and T.B. Gurung. 2001. Nutrition, feed, feeding of golden mahaseer (*Tor putitora*) for domestication and production in Nepal. Symposium on coldwater fishes in the trans Himalayan region, 10-14 July, Kathmandu, Nepal.

Bista J.D., S.K. Wagle, M.K. Shrestha, and A.B. Thapa. 2007. Evaluation of growth performance of Himalayan Sahar (*Tor putitora*) for aquaculture development in mid hills and southern plain of Nepal. Seventh National Workshop on Livestock and Fisheries Research, June 25-27, 2007. Abstracts, pp.12.

Burgess, W.E. 1989. An atlas of freshwater and marine catfishes – a preliminary survey of the Siluriformes. T.F.H. Publications, Inc. United States of America. pp. 784.

Chatterjee, P.K., A. Kumar, and N.D.P. Sinha. 1991. Gonadal cycle and ovarian electrolyte behavior in air-breathing teleosts, *Channa punctatus* (Bloch) and *Heteropneustes fossilis* (Bloch). Journal of Freshwater Biology 3:37-43.

Diana, J.S. 2012. Some principles of pond fertilization for Nile tilapia using organic and inorganic inputs. *In* C.C. Mischke (ed.). Pond Fertilization: Impacts of Nutrient Input on Aquaculture Production. John Wiley and Sons, Inc., New York. pp. 163-177.

DoFD (Directorate of Fisheries Development). 2012. Annual report 2011-2012. Central Fisheries Building, Balaju, Kathmandu, Nepal.

Domingo, J.L., A. Bocio, G. Falco, and J.M. Llobet. 2007. Benefits and risks of fish consumption Part I. A quantitative analysis of the intake of Omega-3 fatty acids and chemical contaminants. Toxicology 230:219-226.

Egna, H., L. Reifke, and N. Gitonga. 2012. Improving gender equity in aquaculture education and training: 30 years of experiences in the Pond Dynamics/Aquaculture, Aquaculture, and AquaFish Collaborative Research Support Programs. Asian Fisheries Science 25S:119-128.

FAO (Food and Agriculture Organization). 1998. Women feed the world. Prepared for World Food Day, 16 October 1998. Rome, Italy. 1 p.

FAO (Food and Agriculture Organization). 2012. Fisheries and Aquaculture topics. Statistics — Introduction. Topics Fact Sheets. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated. [Cited 21 February 2012]. http://www.fao.org/fishery/countrysector/naso_nepal/en

FAO (Food and Agriculture Organization). 2013. National Aquaculture Sector Overview Nepal. National Aquaculture Sector Overview Fact Sheets. Text by Pradhan, G. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 10 October 2005. [Cited 30 May 2013]. http://www.fao.org/fishery/countrysector/naso_nepal/en

FDD, 2009/2010. Annual Progress Report. Fishery Development Directorate, Central Fisheries Building, Kathmandu, Nepal, pp. 110.

GoN (Government of Nepal). 2000. Fisheries perspective plan. Submitted to Inland Aquaculture and Fisheries Development Division. Agricultural Projects Services Centre, Kathmandu, Nepal.

Gurung, T.B., A.K. Rai, P.L. Joshi, A. Nepal, A. Baidhya, J. Bista and S.R. Basnet. 2001. Breeding of pond reared golden mahseer (*Tor putitora*) in Pokhara, Nepal. Coldwater Fish Species in the Trans-Himalayan Region, (10-14 July, 2001), Kathmandu, Nepal.

Hempel, E. 2010. Value Chain Analysis in the Fisheries Sector in Africa. INFOSA. Value Chain Analysis Report. www.fao.org

Jaiswal, R. 2012. Integration of tilapia (*Oreochromis niloticus*) and sahar (*Tor putitora*) in carp polyculture system. MSc Thesis. Institute of Agriculture and Animal Science, Nepal.

Joshi, P.L., T.B. Gurung, S.R. Basnyat, and A.P. Nepal. 2002. Domestication of wild golden mahaseer and hatchery operation. *In*: T. Pert and D.B. Swar (eds.) Cold Water Fisheries in the Trans-Himalayan Countries. FAO Technical Paper No. 431, Rome, pp. 173-178.

Kadir, A., R.S. Kundu, A. Milstein, and M.A. Wahab. 2006. Effects of silver carp and small indigenous species on pond ecology and carp polycultures in Bangladesh, Aquaculture 261:1065-1076.

Kloeblen, S. 2011. The role of women in small scale aquaculture in Nepal. Ecological Aquaculture Studies and Reviews, University of Rhode Island, Kingston.

Mahaffey, K.R., E.M. Sunderland, H.M. Chan, A.L. Choi, P. Grandjean, K. Marlen, E. Oken, M. Sakamoto, R. Schoeny, P. Weihe, C.H. Yan, and A. Yasutake. 2011. Balancing the benefits of n-3 polyunsaturated fatty acids and the risks of methylmercury exposure from fish consumption. Nutrition Reviews 69:493-508.

Mandal J.K., and M.K. Shrestha. 2001. Effect of feed supplementation on growth and production of Nile tilapia in mixed size culture system. Journal of the Institute of Agriculture and Animal Science 21-22:141-149.

MoHP. 2006. Nepal Demographic and Health Survey 2006. Ministry of Health and Population, New Era, and Macro International Inc., Kathmandu.

NACA (Network of Aquaculture Centres in Asia-Pacific). 2010. Regional Review on Status and Trends in Aquaculture Development in Asia-Pacific – 2010. FAO Fisheries and Aquaculture Circular. No. 1061/5. Rome.

NARC (Nepal Agricultural Research Council). 2010. Meeting Nepal's food and nutrition security goals through agricultural science and technology. *In:* NARC's Strategic Vision for Agricultural Research (2011-2030). Nepal Agricultural Research Council, Kathmandu, Nepal.

Oken, E., and M.B. Belfort. 2010. Fish, fish oil, and pregnancy. The Journal of the American Medical Association 304(15):1717-1718.

Pandit, N.P., M.K. Shrestha, Y. Yi, and J.S. Diana. 2004. Polyculture of grass carp and Nile tilapia with napier grass as the sole nutrient input in the subtropical climate of Nepal. *In*: R. Boliver, G. Mair, and K. Fitzsimons (eds.), New Dimension in Farmed tilapia, Proceedings of 6th International Symposium on Tilapia in Aquaculture (ISTA 6), pp. 558-573.

Pantha, M.B. 1993. Aquafeeds and feeding strategy in Nepal. *In*: M.W. New, A.G.T. Tacon, and I. Csavas (eds.), Farm Made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consolation on Farm-Made Aquafeeds, 14-18 December 1992, Bangkok, Thailand. FAO-RAPA/AADCP, Bangkok, pp. 24-60.

Parajuli, R.P., M. Umezaki, and C. Watanabe. 2012. Diet among people in the Terai region of Nepal, an area of micronutrient deficiency. Journal of Biosocial Science 44:401-415.

Paudel, J.K., D.K. Jha, M.K. Shrestha, and J.D. Bista. 2007. Growth performance of Sahar (*Tor putitora*) in different culture systems in Chitwan, Nepal. *In*: R.B. Thapa and M.D. Sharma (eds.), IAAS

Research Advances, Volume 2. Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal, pp. 195-200.

Prasad, M.S., A.P. Mishra, and B.R. Singh. 1993. Induced breeding, larval behaviour and development of the air breathing habit in some freshwater teleosts. *In*: B.R. Singh (ed.). Advances in Fish Research, Vol. 1, pp. 147-168.

Rai, A.K. 2008. Status of sahar (Tor putitora) domestication and its development in the Himalayan Region of Nepal. Aquaculture Asia Magazine, Jan-Mar 2008: 26-32.

Rai, S. 2012. Project Completion Report: Improvement of women's livelihoods, income and nutrition through Carp-SIS polyculture in Terai, Nepal. Institute of Agriculture and Animal Science, Chitwan, Nepal.

Rai, S. 2013. Quarterly Report: Twinning Support to Women Fish Farmers' Organizations in Nepal. Institute of Agriculture and Animal Science, Chitwan, Nepal.

Rai S., M.K. Shrestha, D.K. Jha, and D. Acharya. 2007. Growth performance of Sahar and mixed-sex Nile tilapia in monoculture and co-culture system in Chitwan. *In*: R.B. Thapa and M.D. Sharma (eds.), IAAS Research Advances, Volume 1. Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal, pp. 187-193.

Rai, S., and Y. Yi. 2012. Nibbling frequency of carps in Periphyton-Based Aquaculture Systems with and without Supplemental Feed. Israeli Journal of Aquaculture 64:818-822.

Rai, S., Y. Yi, M.A. Wahab, A. Bart, and J.S. Diana. 2008. Comparison of rice straw and bamboo sticks substrates in periphyton-based carp polyculture systems. Aquaculture Research 39:464-473.

Rajbanshi, K.G. 2001. Zoo-geographical distribution and the status of cold water fishes of Nepal. Symposium on coldwater fishes in the trans Himalayan region, 10-14 July, Kathmandu, Nepal.

Rana, P.J.B., and K.G. Rajbanshi. 1976. National Plan for development of aquaculture in Nepal. *In*: Aquaculture Planning in Asia. Report of the Regional Workshop on Aquaculture Planning in Asia, Bangkok, Thailand, 1-17 October 1975. FAO, Rome.

Roos N., M.A. Wahab, C. Chamnan, and S.H. Thilsted. 2006. Understanding the links between agriculture and health. International Food Policy Research Institute, Washington, D.C.

Roos, N., M.A. Wahab, M.A.R. Hossain, and S.H. Thilsted. 2007. Linking human nutrition and fisheries: incorporating micro-nutrient dense, small indigenous fish species in carp polyculture in Bangladesh. Food and Nutrition Bulletin.

Saxena, P.K., and R. Sandhu. 1994. Influence of temperature on ovarian recrudescence in the Indian catfish, *Heteropneustes fossilis*. Journal of Fish Biology 44:168-171.

Shrestha M.K., R.L Sharma, K. Gharti, and J.S. Diana. 2011. Polyculture of Sahar (*Tor putitora*) with mixed-sex Nile tilapia. Aquaculture 319:284-289.

Shrestha, J. 1994. Fishes, fishing implements and methods of Nepal. Published by Smt. M.D. Gupta, Lalitpur Colony, Lashkar (Gwalior), India, pp. 144.

Shrestha, T.K. 1997. The Mahaseer in the rivers of Nepal disrupted by dams and ranching strategies. Bimala Shrestha, Kathmandu, Nepal, pp. 259.

Shrestha, M.K., and R.C. Bhujel. 1999. A preliminary study on Nile tilapia (*Oreochromis niloticus*) polyculture with common carp (*Cyprinus carpio*) fed with duckweed (*Spirodela*) in Nepal. Asian Fisheries Science 12:83-89.

Shrestha, M.K., J.D. Bista, and Y. Yi. 2007. Performance of *Tor putitora* in sub-tropical climate of Nepal. 8th Asian Fisheries Forum. Asian Fisheries Society and Asian Fisheries Society, Indian Branch, 20 - 23 November 2007, Kochi, India. Fisheries and Aquaculture: Strategic Outlook for Asia, Book of Abstracts, pp. 250-251.

Shrestha, M.K., R. Jaiswal, L. Liping, and J.S. Diana. 2012. Incorporation of tilapia (*Oreochromis niloticus*) and sahar *(Tor putitora*) into the existing carp polyculture system in Nepal. AquaFish CRSP Technical Reports Investigations 2009-2011, Volume 1, August 2012, Oregon State University, Corvalis.

Shrestha, M.K., N.P. Pandit, Y. Yi, J.S. Diana, and C.K. Lin. 2005. Integrated cage-cum-pond culture system with high-valued Sahar (*Tor putitora*) suspended in carp polyculture ponds. *In*: J.

Burright, C. Flemming, and H. Egna (eds.), *Twenty-Second Annual Technical Report*. Aquaculture CRSP, Oregon State University, Corvallies, Oregon, pp. 97-114.

Shrestha, M.K., J. Pant, R.C. Bhujel. 2012. Small-scale aquaculture development model for rural Nepal. *In*: M.K. Shrestha and J. Pant (eds.) Small-scale Aquaculture for Rural Livelihoods: Proceedings of the National Symposium on Small-scale Aquaculture for Increasing Resilience of Rural Livelihoods in Nepal. Institute of Agriculture and Animal Science, Tribhuvan University, Rampur, Chitwan, Nepal, and The WorldFish Center, Penang, Malaysia, pp. 71-75.

Shrestha, M.K., R.L. Sharma, K. Gharti, and J.S. Diana. 2011. Polyculture of sahar (*Tor putitora*) with mixed-sex Nile tilapia. Aquaculture 319:284-289.

Sinha V.R.P. 1993. A compendium of aquaculture technologies for developing countries. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi. 110001, pp. 115.

Speedy, A.W. 2003. Global Production and Consumption of Animal Source Foods. Journal of Nutrition 133:4048S-4053S.

Stepan, Z. 2013. Aquaculture and child nutrition in rural Nepal. Master of Science Thesis, University of Michigan, Ann Arbor (in process).

Stepan, Z., M. Shrestha, and J.S. Diana. 2013. A value chain analysis for carp produced by polyculture in farms of the Chitwan area, Nepal. Final Investigation Report 09MER11UM, AquaFish CRSP, Corvallis, OR (accessed 29 April 2013 at http://aquafishcrsp.oregonstate.edu/UM/).

Tharakan, B., and K.P. Joy. 1996. Effects of mammalian gonadotropin-releasing hormone analogue, Pimozide, and the combination on plasma gonadotropin levels in different seasons and induction of ovulation in female catfish. Journal of Fish Biology 48:623-632.

UNICEF. 2012a. A Milestone Plan Launched to Improve Maternal and Child Nutrition in Nepal.

UNICEF. 2012b. Multi-sectoral Commitment to Improve Maternal and Child Nutrition.

Wahab, M.A., M.A. Alim, and A. Milstein. 2003. Effects of adding the small fish Punti (*Puntius Sophore* Hamilton) and/or Mola (*Amblypharyngodon Mola* Hamilton) to a polyculture of large carp. Aquaculture Research 2003:149-63.

Yadav, C.N.R. 1999. Artificial and semi-artificial propagation of Asian catfish, (Bloch). Thesis No. AS. 99-13. Asian Institute of Technology. Bangkok, Thailand, pp. 68.

Yadav, C.N.R., and A.N. Bart. 2003. Hatchery breeding of catfish, *Heteropneustes fossilis* (Bloch) in Nepal. Journal of the Institute of Agriculture and Animal Science 24:59-66.

Yadav, R.K., M.K. Shrestha, and N.P. Pandit. 2007. Introduction of Sahar (*Tor putitora*) in cage-cum-pond integrated system of mixed-sex Nile tilapia (*Oreochromis niloticus*). Our Nature 5:52-59.

Yi, Y., J.S. Diana, M.K. Shrestha, and C. K. Lin. 2004. Culture of mixed-sex Nile tilapia with predatory snakehead. *In*: R. Boliver, G. Mair, and K. Fitzsimons (eds.) New Dimension in Farmed tilapia, Proceedings of 6^{th} International Symposium on Tilapia in Aquaculture (ISTA 6), pp. 544-557.

Literature Cited, Auburn University

Abdel-Halim, A.M.M. 1992. Microbial protein in fish feeding. Effect of replacement of fishmeal with active and inactive yeast (Saccharomyces cereviseae) on growth performance, carcass composition and feed utilization by tilapia and carps. 2nd Alex. Conf. On Feed Technology. Feb. 1992. Alexandria, Egypt.

Asamoah, E.K., F.K.K. Nunoo, Y.B. Osei-Asare, S. Addo, and U.R. Sumaila (2012) A production function analysis of pond aquaculture in southern Ghana. Aquaculture Economics and Management, 16(3), 183–201.

Ball, A. D., Stapley, J., Dawson, D. A., Birkhead, T. R., Burke, T., and Slate, J. (2010). A comparison of SNPs and microsatellites as linkage mapping markers: lessons from the zebra finch (Taeniopygia guttata). BMC genomics, 11(1), 218.

Baroiller, J. F., D'Cotta, H., and Saillant, E. (2009). Environmental effects on fish sex determination and differentiation. Sexual Development, 3(2-3), 118-135.

Boit, C. Victoria, Ngugi, C. Charles, Bowman James, Oyoo, E. Okoth, Rasowo, J., James, M. Bundi and L., Cherop. 2011. Growth performance, survival feed utilization and nutrient utilization of African catfish (Clarias gariepinus) larvae co-fed Artemia and micro-diet containing freshwater atyid shrimp (Caridina nilotica) during weaning. Journal of Aquaculture Nutrition: 17 2: 82-89 April 2011

Bradley, K. M., Breyer, J. P., Melville, D. B., Broman, K. W., Knapik, E. W., and Smith, J. R. (2011). An SNP-based linkage map for zebrafish reveals sex determination loci. G3: Genes, Genomes, Genetics, 1(1), 3-9.

Buys, Piet, Susmita Dasgupta, and Timothy S. Thomas. 2009. Determinants of a Digital Divide in Sub-Saharan Africa: A Spatial Econometric Analysis of Cell Phone Coverage. World Bank, Washington, DC, United States. World Development Volume 37, Issue 9, September, Pages 1494–1505

Cavalcanti, M. J., Monteiro, L. R., and Lopes, P. R. (1999). Landmark-based morphometric analysis in selected species of serranid fishes (Perciformes: Teleostei). Zoological Studies-Taipei-, 38(3), 287-294.

Chen, J., Hu, W., and Zhu, Z. (2013). Progress in studies of fish reproductive development regulation. Chinese Science Bulletin, 58(1), 7-16.

Chopak, Charles J. (1992). What Brokers, Wholesalers, Retailers, and Restaurants Want: Advice for Food Fish Growers, Michigan Agriculture Experiment Station and the Michigan Department of Agriculture.

DeFaveri, J., Viitaniemi, H., Leder, E. and Merilä, J. (2013), Characterizing genic and nongenic molecular markers: comparison of microsatellites and SNPs. Molecular Ecology Resources.

Dwivedi, A. K., and Dubey, V. K. (2012). Advancements in morphometric differentiation: a review on stock identification among fish populations. Reviews in Fish Biology and Fisheries, 1-17.

Fagbenro, O. and Jauncey, K. 1995. Water stability, nutrient leaching and nutritional properties of moist fermented fish silage diets, Aquacultural Engineering, 14 (2), 143-153.

Frobish, Lowell T. (1991). A Retail Grocery Markets for Catfish, Bulletin 611, Alabama Agriculture Experiment Station.

Garner, S., Birt, T. P., Mlewa, C. M., Green, J. M., Seifert, A., and Friesen, V. L. (2006). Genetic variation in the marbled lungfish Protopterus aethiopicus in Lake Victoria and introduction to Lake Baringo, Kenya. Journal of fish biology, 69(sb), 189-199.

Graber, A. and R. Junge, 2009. Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production, Desalination, 246 (1–3), 147-156.

Hossain, M. B., Rahman, M. M., Sarwer, M. G., Ali, M. Y., Ahamed, F., Rahman, S. Hossain, M. Y. (2013). Comparative Study of Carp Pituitary Gland (PG) Extract and Synthetic Hormone Ovaprim Used in the Induced Breeding of Stinging Catfish, Heteropneustes fossilis (Siluriformes: Heteropneustidae). Our Nature, 10(1), 89-95

Ishak, M.M. 1986. Development of fish farming in Egypt (cage and pen culture). Rep.4 (phase 2) Institute of Oceanography and Fisheries and the International Development Research Centre, Cairo, Egypt. 101pp.

Katengeza, Samson P., Juma Okello and Noel Jambo. 2013 Use of Mobile Phone Technology in Agricultural Marketing: The Case of Smallholder Farmers in Malawi. International Journal of ICT Research and Development in Africa (IJICTRDA) 2 (2). Available at: http://www.igi-global.com/journal/international-journal-ict-research-development/1172 DOI: 10.4018/jictrda.2011070102

Kees P. C., Goudswaard, Frans Witte, and Lauren J. Chapman (2002), Decline of the African lungfish (Protopterus aethiopicus) in Lake Victoria (East Africa) East African Wild Life Society, African Journal of Ecology, 40, 42-52,

Kikuchi, K. and Hamaguchi, S. (2013), Novel sex-determining genes in fish and sex chromosome evolution. Dev. Dyn., 242: 339–353.

Licamele, J. D. 2009. Biomass Production and Nutrient Dynamics in an Aquaponics System. Dissertation, University of Arizona.

Liti, D., Cherop, L., Munguti, J., Chhorn, L. 2005. Growth and economic performance of Nile tilapia (Oreochromis niloticus L.) fed on two formulated diets and two locally available feeds in fertilized ponds. Aquaculture Research, 36 (8) 746–752.

Liu, Z. J., and Cordes, J. F. (2004). DNA marker technologies and their applications in aquaculture genetics. Aquaculture, 238(1), 1-37.

Maina, J G, Beames, R M, Higgs, D. Mbugua, P N, Iwama, G., and Kisia, S M. 2002 Digestibility and feeding value of some feed ingredients fed to tilapia Oreochromis niloticus (L.). Aquaculture Research 33 (11) 853-862.

Marshall, M. (2010). Almost a fifth of vertebrate species endangered. New Scientist, 208(2784), 6-7.

Martin, Brandie and Eric Abbott. 2013. Development Calling: The Use of Mobile Phones in Agriculture Development in Uganda. Greenlee School of Journalism and Communication, Iowa State University:

Mir, J. I., Sarkar, U. K., Dwivedi, A. K., Gusain, O. P. and Jena, J. K. (2013), Stock structure analysis of Labeo rohita (Hamilton, 1822) across the Ganga basin (India) using a truss network system. Journal of Applied Ichthyology.

Mokoro, Anne, Elijah Oyoo-Okoth, Charles C. Ngugi, James Njiru, Joseph Rasowo, Victoria Chepkirui-Boit and David Manguya –Lusega 2013. Effects of stocking density and feeding duration in cage-cum-pond-integrated system on growth performance, water quality and economic benefits of Labeo victorianus (Boulenger 1901) culture. Aquaculture Research 2013, 1-13 Dol: 10.1111/are.12112

Muwanika, V. B., Nakamya, M. F., Rutaisire, J., Sivan, B., and Masembe, C. (2012). Low genetic differentiation among morphologically distinct Labeobarbus species (Teleostei: Cyprinidae) in the Lake Victoria and Albertine basins, Uganda: insights from mitochondrial DNA. African Journal of Aquatic Science, 37(2), 143-153.

Ngugi, C. C., G. Kuria, K. Quagrainie, and S. Macharia. 2011. Effects of Stocking Density on the growth, survival and yield performance of Nile tilapia (Oreochromis niloticus, Linn.1858) in an integrated cage-cum-pond system. The 9th Asian Fisheries and Aquaculture Forum April 21-25, Shanghai Ocean University, China. Oral Presentation

Ogundari, K. and O.O. Akinbogun (2010) Modeling technical efficiency with production risk: A study of fish farms in Nigeria. Marine Resource Economics, 25(3), 295–308.

Onumah, E.E. and H.D. Acquah (2010) Frontier analysis of aquaculture farms in southern sector of Ghana. World Applied Sciences Journal, 9(7), 826–835.

Onumah, E.E., G. Hoerstgen-Schwark, and B. Brummer (2009) Productivity of hired and family labor and determinants of technical inefficiency in Ghana's fish farms. Available at: http://hdl.handle.net/10419/29693 (accessed 16 September 2011).

Pomeroy, Robert S. and Betsy P. Sheehan. (1991). The Market Potential in Selected Markets of the United States and Western Europe for Aquaculture Products from the Southeastern United States, South Carolina Agriculture Experiment Station.

Rakocy, J., Shultz, R.C., Bailey, D.S. and Thoman, E.S. 2004. Aquaponic Production Of Tilapia And Basil: Comparing A Batch And Staggered Cropping System. Acta Hort. (ISHS) 648:63-69.

Rakocy, J.E., D.S. Bailey, J.M. Martin and R. C. Shultz. 2000. Tilapia production systems for the Lesser Antilles and other resource-limited, tropical areas. Pages 651-662 *in* K. Fitzsimmons and J. Carvalho F., Eds. Tilapia Aquaculture in the 21st Century: Proceedings from the Fifth International Symposium on Tilapia in Aquaculture, Rio de Janeiro, Brazil.

Ray, A. 1992. Utilization of diets containing composted aquatic weed (Salvinia cuculata) by the Indian major carp, rohu (Labeo rohita) fingerlings. Bioresource Technology 40(1):67-72.

Strauss RE and Bookstein FL (1982) The truss: body form reconstruction in morphometrics. Syst Zool 31(113–135):1982

Vijaykumar, S., Sridhar, S., and Haniffa, M. A. (1998). Low cost breeding and hatching techniques for the catfish (Heteropneustes fossilis) for small-scale farmers. Naga, the ICLARM Quarterly, 21(4), 15-17.

Wheeler, David. 2009 Does Digital Divide or Provide? The Impact of Cell Phones on Grain Markets in Niger. Center for Global Development, Washington, DC, United States. Available at: http://dx.doi.org/10.1016/j.worlddev..01.011

World Bank. 2013. Module 3: Mobile Devices and Their Impact. World Bank: ICT in Agriculture Sourcebook. Available at: http://www.ictinagriculture.org/sourcebook/module-3-mobile-devices-and-their-impacteferences

Zhang, J., Jiang, Y., Sun, F., Zhang, Y., Wang, R., Li, C., and Liu, Z. J. (2012). Genomic Resources for Functional Genomics in Aquaculture Species. Functional Genomics in Aquaculture, 41-77.Aker, Jenny C., Does Digital Divide or Provide? The Impact of Cell Phones on Grain Markets in Niger (October 1, 2008). Center for Global Development Working Paper No. 154. Available at SSRN: http://ssrn.com/abstract=1093374 or http://dx.doi.org/10.2139/ssrn.1093374

APPENDIX II: ACRONYMS

Program-Related

ACRSP	Pond Dynamics/Aquaculture CRSP
AFCRSP	Aquaculture and Fisheries CRSP
AquaFish	Aquaculture and Fisheries CRSP
CRSP	Collaborative Research Support Program
HC	Host Country
ME	Management Entity
MOU	Memorandum of Understanding
NGO	Nongovernmental organization
PD/ACRSP	Pond Dynamics/Aquaculture CRSP
PI	Principal Investigator
RFA	Request for Assistance
RFP	Request for Proposals

General

FAQ	Frequently Asked Questions
KSh	Kenya Shillings
NB	Nota Bene, note well
PDF	Portable Document Format

Institutions, Organizations, Government Entities and Programs

ACIAR	Australian Centre for International Agricultural Research
AIT	Asian Institute of Technology, Thailand
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
ATA	American Tilapia Association
AwF	Aquaculture without Frontiers, USA
BAU	Bangladesh Aquacultural University
BFAR	Bureau of Fisheries and Aquatic Resources, Philippines
BIOTECMAR	Cultivos and Biotecnologíca Marina C.A., Venezuela
CESASIN	Comite Estatal de Sanidad Acuicola de Sinaloa (Sinaloa State Committee for Aquaculture Sanitation), Mexico
CETRA	Centro de Transferencia Tecnológica para la Acuacultura (Center for Aquaculture Technology Transfer), Mexico
CGIAR	Consultative Group on International Agricultural Research
CI	Conservation International, Mexico
CIAD	Centro de Investigación de Alimentos y Desarrollo (Research Center for Food and Development), Mexico
CIDEA-UCA	Centro de Investigación de Ecosistemas Acuáticos de la Universidad Centroamericana (Center for Research on Aquatic Ecosystems-Central American University), Nicaragua
CIFAD	Consortium for International Fisheries and Aquaculture Development
CIMMYT	International Wheat and Maize Improvement Center, Mexico
CLAR	Central Laboratory for Aquaculture Research, Egypt
CLSU	Central Luzon State University, Philippines
CRC/URI	Coastal Resources Center/University of Rhode Island
CTU	Can Tho University, Vietnam
DASP	Department of Animal Sciences and Production, SUA

DA-BFAR	Department of Agriculture–Bureau of Fisheries and Aquatic Resources, Philippines
EGAT	Bureau for Economic Growth, Agriculture, and Trade (USAID)
EPA	US Environmental Protection Agency
EU	European Union
FAC	Freshwater Aquaculture Center, Central Luzon State University, Philippines
FAO	Food and Agriculture Organization, United Nations
FD	Department of Fisheries, Kenya
FDA	US Food and Drug Administration
FDAP	Fisheries Development Action Plan, Cambodia
FiA	Fisheries Administration, Cambodia
FISH	The FISH Project (Fisheries Improved for Sustainable Harvest), Philippines
FIU	Florida International University
GESAMP	Joint Group of Experts in the Scientific Aspects of Marine Environmental Protection, FAO
GIFT	Genetically Improved Farmed Tilapia Foundation International Inc., Philippines
GOP	Government of Philippines
GTIS	Guyana Trade and Investment Support Project
IAAS	Institute of Agriculture and Animal Science, Nepal
IARC	International Agricultural Research Center(s), CGIAR
ICLARM	International Center for Living Aquatic Resources Management (= The WorldFish Center), Malaysia
IDRC	International Development Research Centre, Canada
IEHA	Presidential Initiative to End Hunger in Africa, USA
IFREDI	Inland Fisheries Research and Development Institute, Cambodia
ISSC	Interstate Shellfish Sanitation Conference
ISA	Sinaloa Institute for Aquaculture, Mexico
ISTA	International Symposium on Tilapia in Aquaculture
KBDS	Kenya Business Development Services, USAID
KNUST	Kwame Nkrumah University of Science and Technology, Ghana
LAC	Latin America and Caribbean Regions
LSU	Louisiana State University
MARENA	Nicaraguan Ministry of the Environment
MRC	Mekong River Commission
MSU	Michigan State University
NAAG	National Aquaculture Association of Guyana
NACA	Network of Aquaculture Centers in Asia, Thailand
NARS	National Agricultural Research System (of Host Countries)
NCSU	North Carolina State University
NIC	National Investment Center
NOAA	National Oceanographic and Atmospheric Administration, USA
NPRS	National Poverty Reduction Strategy, Cambodia
NSF	National Science Foundation, USA
NSSP	National Shellfish Sanitation Program
OSU	Oregon State University
PACRC	Pacific Aquaculture and Coastal Resources Center/University of Hawai'i at Hilo
RIDS-Nepal	Rural Integrated Development Society-Nepal
SEAFDEC/AQD	Southeast Asian Fisheries Development Center/Aquaculture Department, Philippines
SEDPIII	Third Five-Year Socioeconomic Development Plan, Cambodia
SEMARNAT	Secretariat of Natural Resources, Mexico

SOU	Shanghai Ocean University, China
SUA	Sokoine University of Agriculture, Tanzania
SUCCESS	Sustainable Coastal Communities and Ecosystems (EGAT/USAID)
TIES	Training, Internships, Education and Scholarships Program (USAID-Mexico)
TNC	The Nature Conservancy, USA
TTU	Texas Tech University, Lubbock
UA	University of Arizona
UAPB	University of Arkansas, Pine Bluff
UAS	Universidad Autónoma de Sinaloa (Autonomous University of Sinaloa), Mexico
UAT	Universidad Autónoma de Tamaulipas (Autonomous University of Tamaulipas), Mexico
UCA	Universidad Centroamericana (Central American University), Nicaragua
UG	University of Georgia
UHH	University of Hawai'i at Hilo
UJAT	Universidad Juárez Autónoma de Tabasco (Autonomous University of Juarez, Tabasco), Mexico
UJAT-CPSR	Cooperativa Pesquera San Ramón (San Ramón Fisheries Cooperative), Mexico
UBAC	Ujung Batee Aquaculture Center, Banda Aceh, Indonesia
UM	The University of Michigan
URI	University of Rhode Island
US	United States
USA	United States of America
USG	United States Government
USAID	United States Agency for International Development
USEPA	US Environmental Protection Agency, USA
VCA	Value Chain Analysis
VT	Virginia Polytechnic Institute and State University
WAS	World Aquaculture Society
WIOMSA	Western Indian Ocean Marine Science Association
WWF	World Wildlife Fund, USA

Topic Areas

BMA	Production System Design and Best Management Alternatives
FSV	Food Safety, Post Harvest, and Value-Added Product Development
HHI	Human Nutrition and Human Health Impacts of Aquaculture
IND	Climate Change Adaptation: Indigenous Species Development
MER	Marketing, Economic Risk Assessment and Trade
MNE	Mitigating Negative Environmental Impacts
QSD	Quality Seedstock Development
SFT	Sustainable Feed Technology
PDV	Policy Development
WIZ	Watershed and Integrated Coastal Zone Management