Aquaculture Collaborative Research Support Program

Twenty-Third Annual Technical Report

1 August 2004 to 31 July 2005

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INTRODUCTION

The Aquaculture Collaborative Research Support Program (ACRSP) is funded by the United States Agency for International Development (USAID) under authority of the Foreign Assistance Act of 1961 (PL 87-195) as amended and by the universities and institutions that participate in the ACRSP. This cohesive program of research is carried out in selected developing countries and the United States by teams of US and host country researchers, administrators, and students. Now operating under its fourth USAID grant since 1982, the ACRSP is guided by the concepts and direction set down in the Continuation Plan 1996, which was awarded funding under USAID Grant No. LAG-G-00-96-90015-00.

Activities of this multinational, multi-institutional, and multidisciplinary program are administered by Oregon State University (OSU), which functions as the Management Entity (ME) and has technical, programmatic, and fiscal responsibility for the performance of grant provisions.

This report describes research and outreach under taken by the ACRSP from 1 August 2004 to 31 July 2005 and includes projects funded in the eleventh and twelfth work plans. Although abstracts and reports have been edited for style, they are considered published as submitted. The twenty-third Annual Technical Report contains progress abstracts and final reports for projects described in the twenty-third Annual Administrative Report.

The appropriate citation for a report contained within is, for example:
Yang, Y., D. Yan, W. Wang, B. Xiongk, J.S. Diana, and C.K. Lin., 2005. Establishment of links with Chinese institutions in collaboration on aquaculture and environmental impacts. In: K. Kosciuch and H. Egna (Editors), Twenty-third Annual Technical Report. Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 6–15.

BEST PRACTICES FOR MANAGEMENT OF AQUACULTURE POND SOILS IN THAILAND

Twelfth Work Plan, Environmental Impacts Analysis 1 (12EIA1)
Abstract

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Soils in areas for pond culture of carp, catfish, and freshwater prawn in Thailand often are naturally acidic and low in organic matter. Analyses of soils from pond bottoms revealed that aquaculture resulted in increased organic matter concentrations. Ponds are routinely treated with liming materials, and this has tended to increase soil pH. Bottom soil quality was generally best in freshwater prawn ponds, intermediate in carp ponds, and worst in catfish ponds. This finding was not unexpected, because prawn ponds have the lowest inputs of nutrients and organic matter while catfish ponds have the greatest inputs.

Information obtained—on-site characteristics, pond soil composition, and management procedures—has been analyzed. Data suggested that pond bottom soil deteriorates as a function of increasing pond age, and pond management practices are not adequate to maintain good soil quality. Possible relationships between bottom soil quality and external, negative environmental effects have been identified. Best management practices (BMPs) for pond soils are being developed. The BMPs will focus on better methods for determining liming rates, applying liming materials to ponds, and improving bottom soil conditions during the fallow period between crops. In addition, BMPs will emphasize the need to use fertilizers, feeds, and organic wastes efficiently to avoid excessive nutrient and organic matter inputs. Techniques for preventing erosion of ponds and discharge canals also will be included in the BMPs. The BMPs will be translated into the Thai language. The Thailand Department of Fisheries will distribute the BMPs to producers and encourage adoption.

ESTABLISHMENT OF LINKS WITH CHINESE INSTITUTIONS IN COLLABORATION ON AQUACULTURE AND ENVIRONMENTAL IMPACTS

Twelfth Work Plan, Environmental Impacts Analysis 2 (12EIA2)
Final Report

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ABSTRACT

A two-day workshop organized by Aquaculture CRSP, the Asian Institute of Technology, and Huazhong Agricultural University was held on 20 and 21 May 2005 at the International Conference Center, Huazhong Agricultural University, Wuhan, Hubei, China. The objectives of this workshop were to establish links with Chinese institutions for future CRSP research, to identify environmental problems caused by aquaculture and fisheries activities, and to develop researchable topics.

Thirty-four university faculty members, researchers, and students from the University of Michigan, the Asian Institute of Technology (AIT), including representatives from nineteen Chinese universities and research institutes attended the workshop. During the first day of the workshop, speakers introduced Aquaculture CRSP activities and achievements in the past two decades, briefed AIT and its roles in aquaculture development in Asia, overviewed aquaculture development and environmental management in China.

During the second day of the workshop, thirty-one experts identified constraints to aquaculture development and environmental management in China and worked-out a list of prioritized researchable topics.

INTRODUCTION

Aquaculture and culture-based fisheries have developed and intensified rapidly in China since the late 1970s, and have played important roles in the livelihood of Chinese farmers through employment, income generation, and food security. China produces about 70% of the world's farmed aquatic products. Technology development in aquaculture, driven by farmers' initiatives, research efforts by universities and relevant research institutes, and extension by government agencies has made great progress in the last several decades. However, information exchange between China and other countries, as well as international cooperation, is still at a small scale in limited areas and with few institutions involved.

Massive and rapid development of aquaculture and culture-based fisheries has also raised concerns about aquatic environments. Lack of environmental awareness and environmentally friendly technologies have resulted in improper aquaculture practice, causing pollution in most public waters such as rivers, lakes, and reservoirs. In addition, with intensification of aquaculture systems, heavy uses and abuses of chemicals and drugs are imposing threats to food safety and sustainable use of those waters for fishery production. Furthermore, many dams are constructed on streams and rivers to create water bodies for various purposes including fish production. The impacts of dams and related fishery activities on natural aquatic ecosystems and native biodiversity have yet to be assessed properly and relevant issues urgently need to be addressed. China also has the largest number of exotic aquatic species in the world. Attention should be directed to potential impacts of fishery development on biodiversity, and appropriate control mechanisms established.

Aquaculture CRSP has conducted research and outreach activities in Asia for more than two decades. Its efforts on both fundamental and applied research in aquaculture to promote environmentally friendly aquaculture practice, natural resource conservation, and environmental protection have made significant advances in various host countries. Extending its collaboration linkages to China, the largest aquaculture producer in the world would create opportunities to address problems faced by global aquaculture.

With the ultimate goals to address environmental issues related to aquaculture and fisheries activities for promoting sustainable development of aquaculture and cultured-based fisheries in China, a workshop was proposed with the following objectives:

1. To establish links with Chinese institutions for future ACRSP research.
2. To identify environmental problems caused by aquaculture and fisheries activities and develop researchable topics.

Workshop organization and participants

A two-day workshop organized by Aquaculture CRSP, the Asian Institute of Technology and Huazhong Agricultural University was held on 20 and 21 May 2005 at the International Conference Center, Huazhong Agricultural University, Wuhan, China. The workshop consisted of two parts: a technical session and an expert panel meeting.

A total of thirty-four university faculty members, researchers, and students attended the workshop. Among the participants, twenty-eight were from nineteen Chinese universities and research institutes, while two came from the University of Michigan, and four from the Asian Institute of Technology. The participants included three students: one PhD student and one MS student from Huazhong Agricultural University, and one PhD student from AIT (Table 1).

Technical Presentations

The workshop was opened by a welcome address by Prof. Xie Conghua, the vice president of Huazhong Agricultural University, and a welcome address by Dr. Yang Yi, the Asian Institute of Technology. Prof. James Diana briefly overviewed the history of Aquaculture CRSP and overviewed its global activities, and Prof. C. Kwei Lin introduced the major activities and achievements of Aquaculture CRSP in Asia during the past two decades. Dr. Amrit Bart gave an introduction to the Asian Institute of Technology and its roles in aquaculture development in Asia.

Prof. Wang Weimin of Huazhong Agricultural University chaired the technical session. Seven technical presentations concerning aquaculture development and environmental impacts were given by Chinese participants, two in the morning and five in the afternoon (Table 2).

Dr. Liu Zhengwen from Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, discussed the environmental change in last two decades in Lake Taihu in central Yangtze River delta, the third largest freshwater lake in China. Satellite images and ground sampling data clearly showed deterioration of water quality in the lake over time.

Table 1. List of participants for Aquaculture CRSP Workshop on aquaculture development and environmental management in China.

Name	Gender	Nationality	Institution
Prof. James Diana	M	American	University of Michigan
Prof. C. Kwei Lin	M	American	University of Michigan
Dr. Yang Yi	M	Chinese	Asian Institute of Technology
Dr. Amrit Bart	M	American	Asian Institute of Technology
Dr. Amararatne Yakupitiyage	M	Sri Lankan	Asian Institute of Technology
Mr. Yuan Derun	M	Chinese	Asian Institute of Technology (PhD student)
Dr. Yan Xizhu	M	Chinese	Fisheries College, Jimei University
Dr. Su Yongquan	M	Chinese	Ocean College, Xiamen University
Dr. Yao Weizhi	M	Chinese	Fisheries College, Southwest Agricultural University
Dr. Zhou Xiaoqiu	M	Chinese	Sichuan Agricultural University
Prof. Lai Qiuming	M	Chinese	Ocean College, Hainan University
Prof. Miao Weimin	M	Chinese	Freshwater Fisheries Research Centre, Chinese Academy of Fishery Sciences
Prof. Shao Qingjun	M	Chinese	College of Animal Science, Zhejiang University
Dr. Liu Zhengwen	M	Chinese	Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences
Prof. Zou Guiwei	M	Chinese	Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences
Prof. Liu Qigen	M	Chinese	Shanghai Fisheries University
Dr. Wang Chaoyuan	M	Chinese	Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences
Dr. Li Gu	M	Chinese	Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences
Prof. Han Deju	M	Chinese	Institute of Water-Engineering Ecology, Ministry of Water Resources and Chinese Academy of Sciences
Prof. Wang Liang	M	Chinese	Hubei Fisheries Research Institute
Prof. Zhang Hong	M	Chinese	Hubei Fisheries Research Institute
Prof. Zhang Tanglin	M	Chinese	Hydrobiological Research Institute, Chinese Academy of Sciences
Prof. Song Biyu	F	Chinese	School of Resource and Environmental Science, Wuhan University
Dr. Huang Feng	M	Chinese	Polytechnic College of Wuhan
Dr. Xiong Bangxi	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Wang Weimin	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Zhu Bangke	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Shen Jianzhong	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Wei Kaijian	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Liu Xiaoling	M	Chinese	Fisheries College, Huazhong Agricultural University
Dr. Ma Xufa	F	Chinese	Fisheries College, Huazhong Agricultural University
Mr. Liu Yulin	M	Chinese	Yangtze University
Mr. Zhang Xuezhen	M	Chinese	Fisheries college, Huazhong Agricultural University (PhD student)
Miss Cao Ling	F	Chinese	Fisheries college, Huazhong Agricultural University (MS student)

Table 2. Topics presented at the Aquaculture CRSP Workshop on aquaculture development and environmental management in China.

Presenter	Institution	Topics
Prof. James Diana	University of Michigan	Overview of Aquaculture CRSP
Prof. C. Kwei Lin	University of Michigan	Introduction of Aquaculture CRSP activities in Asia
Dr. Amri Bart	AIT	Roles of AIT in aquaculture development in Asia
Dr. Liu Zhengwen	Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences	Changes in the environment and fisheries of Tai Lake
Dr. Yan Xizhu	Fisheries College, Jimei University	Impacts of intensive oyster culture on coastal environment
Prof. Yao Weizi	Fisheries College, Southwest Agricultural University	Boat net cage fish farming in rivers and its environmental effects
Mr. Liu Qigen	Shanghai Fisheries University	Harmonizing lake fishery and the aquatic environment—Aquatic Environment Protection Oriented (AEPO)
Miss Cao Ling	Fisheries College, Huazhong Agricultural University	Current status of pond aquaculture and waste management in China
Prof. Lai Qiumin	Ocean College, Hainan University	Coastal aquaculture and environmental problems in Hainan Province
Dr. Wei Kaijian	Fisheries College, Huazhong Agricultural University	Thoughts on the current status and development of China's freshwater aquaculture

Prof. Yan Xizhu from Jimei University presented the environmental impacts of intensive oyster culture on Tangan Bay of Fujian province in Southern China. The results clearly showed that intensive oyster culture has significant impacts on ecosystem and environment, and the culture biomass of bivalves exceeds carrying capacity of the coastal ecosystem.

Prof. Yao Weizi from Southwest Agricultural University presented information on boat-framed, net cage fish farming in rivers, a popular inland aquaculture practice in China, and its environmental effects. He mentioned that the boat-framed, net cage fish farming might be a suitable form of aquaculture in the newly formed Three Gorges Reservoir; however, systematic research is needed on the environmental impacts of cage culture and carrying capacity.

The presentation by Prof. Liu Qigen from Shanghai Fisheries University was on aquatic environmental protection and fisheries in Lake Qiandaohu, a picturesque tourist attraction surrounded by thick forests, where very little point source pollution exists. His research indicated that maintaining a certain amount of biomass of silver and bighead carps can control algae bloom and improve water quality in lakes.

Ms. Cao Ling, an MS student of Huazhong Agricultural University, examined production practices and waste management aspects of pond aquaculture in China. Current practices for waste management in freshwater pond aquaculture in China are not effective or efficient enough to safeguard the environment and further research is needed to develop environmentally friend aquaculture.

Prof. Lai Qiuming from Hainan University overviewed coastal aquaculture development in Hainan province, a tropical island where coastal aquaculture has developed rapidly in recent years. After presenting production details, problems and some remedying measures to the problems, he concluded that coastal aquaculture provides large employment opportunities and generates significant income for coastal communities. However, rapid coastal aquaculture development without careful planning and regulations has caused serious environmental degradation in bays and estuaries. The industry needs to strengthen research interest and capability.

Dr. Wei Kaijian from Huazhong Agricultural University overviewed the history and current status of freshwater aquaculture in China. He also listed various constraints and critical issues in freshwater aquaculture and offered his views on aquaculture research priorities for sustainable development. A general discussion followed the technical presentations. The technical session ended with closing remarks by Prof. James Diana.

Expert panel meeting

The second part of the workshop was an expert panel meeting. The goal of this panel meeting was to identify constraints to aquaculture development and environmental management in China and to finalize a list of research priorities for sustainable aquaculture development. All thirty-four workshop participants attended the expert panel meeting. Prof. James Diana, Dr. Amrit Bart, and Dr. Yang Yi acted as moderators.

Prof. James Diana opened the meeting by extending a warm welcome to all participants. Dr. Amrit Bart and Dr. Yang Yi outlined the purpose of the meeting and explained the ground rules for the practice.

Developing the list of constraints

Each participant was asked to list the top five most important constraints to aquaculture development and environmental management in China on note cards, incorporating stakeholder consideration, information from the literature, and their knowledge. Dr. Amrit Bart then asked panel participants to read and explain the constraints from their note cards. Prof. James Diana recorded all constraints on flip charts, while Dr. Yang Yi entered them into a computer.

Prioritizing the List of constraints

Each participant was given 5 dots for use in identifying the constraints had the most importance. As a result, a list of 59 constraints was prepared (Table 3). The constraints with at least one vote were grouped into seven broad constraints written in constraint language (Table 4). Then, each participant was again given 5 dots for use in identifying which broad constraints had the most importance. The final list of prioritized major constraints is presented in Table 4.

Researchable priories arising from constraints

Participants were divided into five groups. Major constraints in Table 4 were assigned to each group: insufficient attention on biodiversity, genetics and breeding of indigenous species (Group 1); inappropriate management of open-water aquaculture and culture-based fisheries (Group 2); lack of appropriate pond management and waste treatments, and insufficient support on improving integrated/polyculture systems (Group 3); inappropriate health management and lack of control on food safety, and insufficient support on enhancing education on aquaculture and environment (Group 4); and insufficient research on nutrition, feed and feeding management (Group 5). Each group was asked to develop researchable topics on each constraint. Results were recorded on flip charts, and listed researchable topics were placed along with the constraints. The group then edited the researchable topic list shown in Table 5.

Table 3. List of constraints to aquaculture development and environment management in China finalized during the expert panel meeting.

Number	Constraints	Weight (dots)
1	Breeding of indigenous species	12
2	Influence of aquaculture wastewater discharge on lakes and rivers	0
3	Best methods for waste disposal and environmental impacts	5
4	Water monitoring and treatment for quality of discharged water from ponds	0
5	Better understanding of microorganisms roles, especially for phosphorus	1
6	Nutrition, feed and feeding management for both freshwater and marine	4
7	Biodiversity research in freshwater	14
8	Cage culture technology research	0
9	Control of algal blooms	0
10	Technology to protect the freshwater environment	1
11	Environmental impact for different kinds of feeds	1
12	Food safety and quality control methods	2
13	Effects of feed on food safety	1
14	Impacts of crab pen culture on environment of macrophytes dominated lakes	2
15	Impacts of cage culture on rivers, lakes and reservoirs	3
16	Niche and impacts of exotic species	8
17	Identify internal substances related to digestion of fish	0
18	Optimum capacity of different trophic types of lakes and reservoirs	9
19	Technology for water quality management in ponds	0
20	Evaluation and restoration of aquatic ecosystems	0
21	Influence of dams on the fisheries resources	2
22	Using macrophytes to improve water quality	1
23	Impact of filter feeding fish and shellfish on plankton	0
24	Source and eutrophication of lakes and reservoirs	1
25	Biomanipulation for water quality	2
26	Developing environmental friendly feeds	1
27	Mud treatment methods for ponds	0
28	Technology to prevent fish stress	2
29	Dynamics of different aquaculture practices and nutrient budget	3
30	Efficient utilization of wastewater in aquaculture	2
31	Impacts of culture-based fisheries on natural environment, especially silver and bighead carps and ice fish	5
32	Technology for effective manipulation of culture environment	0
33	Genetic improvement of culture species	2
34	Natural carrying capacity of lakes, reservoirs and bays	0
35	Technology to reduce nutrient discharged from ponds	0
36	Waster saving aquaculture methods	0
37	Understanding integrated aquaculture-aquaculture systems for coastal and freshwater aquaculture	7
38	Water quality monitoring in natural waters	0
39	Domestication and culture of new marine species	0
40	Monitoring of aquaculture product safety	0
41	Health management: Disease diagnosis and treatment Understanding of diseases mechanism	5
42	Fishery policy and regulations	0
43	Effectiveness of artificial wetland for wastewater treatment	7
44	Standard for effluent discharge from ponds	0
45	How to balance production and environment	0
46	Culturing technologies for live foods	4
47	Use of aquaculture to control parasite of humans	1

Table 3 Continued

48	Ecological understanding for aquaculture management in natural water bodies	6
49	Establishing a database of Chinese aquaculture	0
50	Changing from aquaculture to ecotourism in open-water	0
51	Effects of overfishing on fisheries resources	3
52	Causes and treatment for stunting	0
53	Curriculum development on aquaculture and environment	2
54	Good management practices for major culture species	0
55	Technology for offshore net cage culture	2
56	Technology to convert exotic plant to value added products	1
57	Reuse of sediments and wastewater	5
58	Abuse and overuse of medicines and chemicals in aquaculture	1
59	Extension to include environmental issues in aquaculture	0

Table 4. List of prioritized major constraints to aquaculture development and environment management in China with ranking finalized in the expert panel.

Rank Number	Prioritized constraints in constraint language	Original constraints from Table 3	Weight (dots)
1	Insufficient attention to biodiversity, genetics, and breeding of indigenous/endangered species	#1, 7, 16, 21, 33, & 51	41
2	Inappropriate management of open-water aquaculture and culture-based fisheries	#10, 14, 15, 18, 22, 24, 31, 48, 55 & 56	32
3	Lack of appropriate pond management and waste treatment	#3, 5, 25, 29, 30, & 43	20
4	Insufficient support on improving integrated/ polyculture systems	#22, 37, & 57	13
5	Inappropriate health management and lack of control on food safety	#12, 28, 41, 47, & 58	12
6	Insufficient research on nutrition, feed and feeding management	#6, 11, 13, 26 & 46	11
7	Insufficient support on enhancing education on aquaculture and environment	#53	2

Table 5. List of researchable topics for aquaculture development and environmental management in China.

Group	List of developed researchable topics for aquaculture and environment in China
1	Insufficient attention to biodiversity, genetics and breeding of indigenous/endangered species • Development of cryopreservation protocol for sperm from three species of sturgeons and Chinese sucker • Population structure and genetic diversity of three species of sturgeons and Chinese sucker using microsatellite marker • Genetic diversity of the main cultured freshwater fishes in China • Selective breeding and genetic improvement of mainly cultured species in China
2	Inappropriate management of open-water aquaculture and culture-based fisheries • Comparison of indigenous species composition among lakes with and without large-scale stocking of icefish • Identification of habitats and the geographic stocks of Chinese sucker and the four carps in the Yangtze River by otolith microchemistry • Comparison of different stocking strategies to commercially improved aquatic animals like piscivorous mandarin fish (*Sineperca chuatsi*), and Chinese mitten crab (*Ereicheir sinensis*) in shallow lakes along the Yangtze River, with emphasis on their ecological impacts on the food web • Effects of silver and bighead carp on water quality and plankton community in deep lakes such as Qiandao Lake • Impacts of intensive marine culture on the ecosystem (biodiversity, physical, chemical and biological parameters) and sediment in Tongan Bay • Comparison of different spatial patterns of pen-culture for crabs in macrophyte dominated lakes • Assess environmental impacts of boat-cage culture in rivers • Determination of stocking density of paddlefish based on zooplankton biomass in Daoguanhe Reservoir • Determination of stocking densities of silver and bighead carps based on plankton biomass in shallow algal-dominated lakes
3	Lack of appropriate pond management and waste treatment • Use of filter feeders (carps) and macrophytes to treat effluent from intensive pond culture • Comparison between constructed wetlands and sedimentation ponds to treat waste effluent from intensive fish ponds • Effects and mechanism of microorganisms on water quality in intensive fish ponds • Develop and test sinking probiotic pellets for pond bottom treatment
4	Insufficient support on improving integrated/polyculture systems • Effectiveness of integrated cage culture and seaweed culture in coastal aquaculture • Assessment of seaweed and intensive shrimp culture on resource recovery and economic gain
5	Inappropriate health management and lack of control on food safety • Use of aquaculture to control parasites of humans: adaptive field of application of bio-economic models to control *Oncomelania hupensis* mosquito larvae and water pollution in aquaculture water • Health management: compare effects of different stimulants on the immunity in *Acipenser sabryanus* and *A. schrenckii*
6	Insufficient support on nutrition, feed and feeding management • Development of optimum feeding schedules to minimize P and N waste from aquaculture feed on crucian carp • Improvement of digestibility of on-farm feed prepared with local ingredients on crucian carp • Reduction/elimination of antinutritional factors in farm feed ingredients • Improved feed utilization efficiency of crucian carp by balancing vitamin and mineral requirements • Dietary P requirements for crucian carp and black sea bream, and utilization of different P sources (fishmeal), plant sources (soybean meal, wheat bran, corn meal), minerals ($Ca(PO_4)_2$, $CaHPO_4$, $Ca(H_2PO_4)_2$) by crucian carp and black sea bream • Lipid requirement and its metabolism controlled by caritine on crucian carp and black sea bream

Table 5 Continued

7	Insufficient support on enhancing education on aquaculture and environment • Improve curriculum with emphasis on aquaculture and environment

Ranked researchable priorities

Each participant was given 5 dots for use in identifying which researchable topics had the most importance. As a result, a list of 27 prioritized researchable topics was prepared (Table 6).

CLOSING COMMENTS

Dr. Amrit Bart summarized the expert panel meeting, while Prof. C. Kwei Lin thanked all participants for their great contribution to the workshop on aquaculture development and environmental management in China, and wished to work with Chinese participants on future Aquaculture CRSP activities.

Table 6. List of prioritized researchable topics for aquaculture development and environmental management in China with ranking finalized in the expert panel meeting.

Rank	List of prioritized researchable topics for aquaculture and environment in China	Weight (dots)
1	Selective breeding and genetic improvement of mainly cultured species in China	12
2	Identification of habitats and the geographic stocks of Chinese sucker and the four carps in the Yangtze river by otolith microchemistry	9
3	Comparison between constructed wetlands and sedimentation ponds to treat waste effluent from intensive fish ponds	9
4	Dietary P requirements for crucian carp and black sea bream, and utilization of different P sources (fishmeal), plant sources (soybean meal, wheat bran, corn meal), minerals ($Ca(PO_4)_2$, $CaHPO_4$, $Ca(H_2PO_4)_2$) by crucian carp and black sea bream	8
5	Effects of silver and bighead carp on water quality and plankton community in deep lakes such as Qiandao Lake	8
6	Development of cryopreservation protocol for sperm from three species of sturgeons and Chinese sucker	6
7	Population structure and genetic diversity of three species of sturgeons and Chinese sucker using microsatellite marker	6
8	Comparison of indigenous species composition among lakes with and without large-scale stocking of icefish	6
9	Health management: compare effects of different stimulants on the immunity in *Acipenser sabryanus* and *A. schrenckii*	6
10	Impacts of intensive marine culture on the ecosystem (biodiversity, physical, chemical and biological parameters) and sediment in Tongan Bay	6
11	Genetic diversity of the main economic cultured freshwater fishes in China	5
12	Effects and mechanism of microorganisms on water quality in intensive fish ponds	5
13	Effectiveness of integrated cage culture and seaweed culture in coastal aquaculture	5
14	Comparison of different spatial patterns for pen-culture of crabs in macrophyte-dominated lakes	5
15	Assessment of seaweed and intensive shrimp culture on resource recovery and economic gain	4
16	Use of aquaculture to control parasites of humans: adaptive field of application of bio-economic models to control *Oncomelania hupensis* mosquito larvae and water pollution in aquaculture water	4
17	Assess environmental impacts of boat-cage culture in rivers	3
18	Determination of stocking density of paddlefish based on zooplankton biomass in Daoguanhe Reservoir	3
19	Determination of stocking densities of silver and bighead carps based on plankton biomass in shallow, algal-dominated lakes	3
20	Comparison of different stocking strategies to commercially improvement aquatic animals like piscivorous mandarin fish (*Sineperca chuatsi*), and Chinese mitten crab (*Ereicheir sinensis*) in shallow lakes along the Yangtze River, with emphasis on their ecological impacts on the food web	3

Table 6 Continued

21	Use of filter feeders (carps) and macrophytes to treat effluent from intensive pond culture	2
22	Development of optimum feeding schedules to minimize P and N waste from aquaculture feed on crucian carp	1
23	Develop and test sinking probiotic pellets for pond bottom treatment	1
24	Improvement of digestibility of on-farm feed prepared with using local ingredients on crucian carp	0
25	Reduction/elimination of antinutritional factors in/on farm feed ingredients	0
26	Improved feed utilization efficiency of crucian carp by balancing vitamin and mineral requirements	0
27	Lipid requirement and its metabolism controlled by caritine on crucian carp and black sea bream	0

ANTICIPATED BENEFITS

This workshop will be important to increase public awareness on aquaculture-related environmental issues through education, research, and outreach in China. The workshop helped Aquaculture CRSP researchers understand more about the current status of aquaculture development and environmental management practices in China. The expert panel meeting successfully identified major constraints to aquaculture development and environmental management in China, and listed researchable prioritizes arising from these constraints. In addition, the outcome of the expert panel meeting in the form of ranked researchable priorities will assist Aquaculture CRSP in developing research proposals to promote sustainable aquaculture in China in collaboration with Chinese institutions.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support from Huazhong Agricultural University. Special thanks are extended to Mr. Zhang Xuezhen, Miss Cao Ling, and other students of Huazhong Agricultural University for providing all logistic arrangements.

IMPACT OF NILE TILAPIA (*OREOCHROMIS NILOTICUS*) INTRODUCTION ON THE INDIGENOUS SPECIES OF BANGLADESH, NEPAL, AND CAMBODIA

Twelfth Work Plan, Environmental Impact Analysis 3 (12EIA3)
Abstract

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The objective of this study is to assess the impact of introducing mixed-sex and male Nile tilapia on three important indigenous fish species of Bangladesh and Nepal. The study is being conducted in small ponds where changes in population structure and recruitment are being assessed over time. This study consists of two experiments, which are being conducted in both Bangladesh and Nepal.

Experiment 1: This experiment is being conducted in nine 100 m2 earthen ponds at the Field Laboratory of the Fisheries Faculty at Bangladesh Agricultural University in Mymensingh, Bangladesh, to asses the impact of mixed-sex and male mono-sex Nile tilapia on mola (*Amblypharyngodon mola*), chela (*Chela cachius*), and punti (*Puntius sophore*). Fish population structure and recruitment rates are being assessed over time, and the dietary overlap between tilapia and these indigenous species is being evaluated. The experiment commenced on 8 December 2004 and will continue for 20 months. A completely randomized design with three treatments and three replications per treatment is being used. The treatments are (i) mixed-sex tilapia with the three indigenous fish species; (ii) mono-sex male tilapia with the indigenous species; and (iii) the indigenous species without tilapia (control). Before stocking, all ponds were drained completely to ensure that no other fish were present. The ponds were then filled and limed (250 kg ha-1 of CaCO3), manured (1000 kg ha-1 of cow dung), and fertilized (100 kg ha-1 of urea and 50 kg ha-1 of STP) one week prior to stocking. Each species was apportioned equally (25%) within a total stocking rate of 0.56 fish m-2 for the two tilapia treatments (i and ii). Each indigenous species was apportioned equally (33%) within a total stocking rate of 0.42 fish m-2 for the control (iii). The male to female ratio of indigenous species was 1:1. Nile tilapia were stocked 74 days after the indigenous species were stocked. There was no additional nutrient input to the ponds after the indigenous species were stocked. Individual lengths and weights of a sample of fish were determined during stocking. The initial average weight of mola, chela, punti, and tilapia was 0.68, 0.73, 4.54, and 5.12 g, respectively.

Monthly fish sampling is being conducted to observe the fish population structure. Recruitment (offspring resulting from spawning) of each species is being enumerated during monthly sampling to estimate total recruitment of each species. Batch weights of newly recruited fish are being taken.

The lengths and weights of individual fish are being measured and recorded from a sample of each fish generation. Water quality analyses are being conducted bi-weekly for water temperature, dissolved oxygen, pH, transparency, total ammonia nitrogen, nitrite-N, nitrate-N, total suspended solids, and alkalinity and monthly for plankton and chlorophyll-*a*. Twelve months after stocking, gut analyses will be performed on each species to determine the Electivity Index and Dietary Overlap. Results to date indicate that mola and punti spawned only one time in all treatments during the period of March to May and April to June, respectively. Chela has not spawned. Spawning has occurred in all replications of mixed-sex Nile tilapia.

Experiment 2: This experiment is being conducted in nine 100 m2 earthen ponds at the Institute of Agriculture and Animal Science in Rampur, Chitwan, Nepal to asses the impact of mixed-sex and male mono-sex Nile tilapia on chandapothi (*Puntius sophore*), darai (*Esomus danricus*), and faketa (*Barilius barna*). The objectives, treatments, experimental design, and procedures of Experiment 2 are the same as in Experiment 1 with the following exceptions. The experiment commenced on 4 June 2005. The ponds were fertilized with 80 kg ha-1 of urea and 50 kg ha-1 of STP one week prior to stocking. Nile tilapia were stocked 30 days after the indigenous species were stocked. The initial average weight of chandapothi, darai, faketa, and tilapia was 6.30 g, 2.00 g, 3.50 g, and 28.38 g, respectively.

Results to date indicate that chandapothi and darai spawned in all treatments and replications, and faketa spawned only in one replicate of the control. Spawning has occurred in two replications of the mixed-sex Nile tilapia treatment.

BUILDING THE CAPACITY OF MOI UNIVERSITY TO CONDUCT WATERSHED ASSESSMENTS

Twelfth Work Plan, Environmental Impacts Analysis 4 (12EIA4)
Abstract

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A major barrier to socioeconomic development in sub-Saharan Africa, including Kenya, is food inadequacy. Some of the more important factors that have led to this status are rapid population growth outstripping food production capacity, post-harvest losses, land degradation that leads to further decline in soil fertility, and climatic changes, particularly periodic droughts and subsequent flooding. These food shortages, coupled with high poverty rates that diminish people's ability to afford the ever-increasing food prices, have led to related health problems, especially in rural areas. In an effort to meet the required food supplies to feed the growing population, forestlands have been cleared for small-scale agriculture. Inevitably, a major challenge to economic development in Kenya is the sustained increase of food production without compromising the integrity of the environment within which that much needed food is produced. As such, the project seeks to complement other projects that seek to "improve the productivity and sustainability of land use systems in Nzoia, Yala, and Nyando river basins through adoption of an integrated ecosystem management approach" through development of on-farm and off-farm conservation practices and increased local capacity. Desired outcomes include increased biodiversity and reduced erosion.

Such a balance reflects decision-making regarding risk. People must balance the need for meeting food, housing, and health needs with an interest in protecting the environment. Risk approaches require an integration between positivist and constructivist approaches. Risk not only appears as a function of probability to consequence dynamics, but also as a function of risk perception and responses to risk perception.

We envision Moi University as a regional center for the Nzoia basin management. This center will provide a basis for cooperation and stimulation with other projects in Kenya that are ongoing in the Njoro basin, where Edgerton University is playing a lead role. A recent visit was made to begin progress toward each of the project objectives. The major issues discussed included capacity building, budget concerns, and science issues, with progress made on each concerns. The GIS lab will be built around the following new equipment: a) Computer running Windows XP; b) GIS software (Arc View); c) Scanner; d) Digitizer; and e) Plotter.

Discussions were held with Moi University administrators regarding placement of the GIS lab on the Moi campus. Moi regards this lab as an integral part of their long-range plan to expand offerings in the environmental science area in the next few years. Moi has committed to find space for the computer laboratory and the increasing project library collection.

LAND-USE PRACTICES, POLICY, AND TENURE REGIMES IN THE NZOIA RIVER BASIN

Twelfth Work Plan, Environmental Impacts Analysis 5 (12EIA5)
Abstract

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Perhaps the single most important variable in achieving sustainable watershed management is understanding and underpinning key land use practices that directly or indirectly affect ecological processes and system functioning. The reliance on land for agrarian production in rural Kenya coupled with dependence on land resources for economic livelihood places enormous premium on resources derived from land and as a consequence leads to degradation and hence loss of ecological integrity of the system. A sustainable land management strategy requires not only site-specific intervention but also at the landscape level. A system approach is needed to disentangle critical landscape components and linkages and will more likely lead to overall positive impacts on the watershed. The Nzoia watershed system transcends a broad range of land use systems and practices ranging from small scale holder farmland to large scale mechanized agriculture and cuts across a tenure regime of private ownership to public land (e.g., forest reserves and national parks). The watershed occurs in generally high potential and high population regions of the country, and therefore the influence of land use on the system is extremely important.

Aside from the analysis of land use practices and associated possible environmental effects, another key aspect of this component is to examine the role and influences of prevailing policies and laws as drivers of land use practice—the extent to which the land use systems and practices are guided or influenced by existing laws and policies. An understanding of how much overlap or synergy exists between various land-related policies and legislation and how these might impede sustainable land use management at the site specific level and overall watershed system. How much environmental/land use policy and legislative awareness exists among the rural population within the watershed? What policies or legal provisions exist for mitigating negative environmental impacts of land use practices, e.g., use of pesticides and herbicides? These are some of the critical questions that need to be addressed in this component.

Subsequent discussions are refining the curriculum for an in-country three- to five-day workshop on techniques for applying GIS to watershed assessment. Personnel from the nearby group at Njoro (Edgerton University) were present and contributed a valuable perspective to the discussions.

WORKSHOPS ON GUIDELINES FOR DEVELOPING AQUACULTURE BEST MANAGEMENT PRACTICES

Twelfth Work Plan, Environmental Impacts Analysis 6 (12EIA6)
Abstract

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PowerPoint slides and a manuscript have been developed as aids for presenting Aquaculture Best Management Practices (BMP) workshops. The slides are arranged into three sets. The first is entitled "Aquaculture and the Environment." It provides information on the importance of aquaculture, describes aquaculture systems and production practices, and considers possible negative environmental and social impacts of aquaculture. The second set of slides, "Codes of Conduct and Best Management Practices" gives details about the response of the aquaculture industry, international development organizations, governments, and environmental advocacy organizations to concerns over aquaculture and the environment. These responses have been expressed mainly in efforts to encourage producers to apply BMPs designed to avoid negative impacts. The third set of slides describes the process that should be followed in developing aquaculture BMPs. The process should include environmental survey, impact assessment, and development of practices to prevent impacts. Particular attention should be given to involvement of a wide range of stakeholders and a thorough dialogue of the issues surrounding BMPs.

The manuscript "Best Management Practices for Responsible Aquaculture" is intended as a more thorough version of the information presented in the slides. In addition to the slides and manuscript, local environmental experts will be used as resource people and speakers in the workshops to provide country-specific information.

The first BMP workshop will be held at the 7th Biannual Meeting of the Aquaculture Association of Southern Africa in Grahamstown, South Africa (12–16 September 2005). The second workshop will be held in Brazil in March 2006. Following each workshop, the slides and manuscript will be revised to correct deficiencies found during their use. The manuscript is intended for publication as an Aquaculture CRSP manual. It also will be translated into Portuguese and published in a Brazilian scientific journal. If it is desired to convene workshops at other locations, the material used for the first two workshops will be available.

REPRODUCTIVE PERFORMANCE AND GROWTH OF IMPROVED TILAPIA, *OREOCHROMIS NILOTICUS*

Eleventh Work Plan, Sustainable Development and Food Security 3 (11SDFR3)
Final Report

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ABSTRACT

This study compared the growth, survival, sexual maturation, and various reproductive parameters of four tilapia strains, three of which have been improved through various selective breeding approaches (GIFT, IDRC and Fishgen-selected); a local stock (Chitralada) was included as a non-improved control. The four strains were originally cultured in extensive culture systems with fertilization only. Growth (weight and length) and reproductive parameters (gonadosomatic index, hepatosomatic index, and stages of sexual maturation) were measured on fish sampled every 21 days. No strain specific growth differences were observed when grown in extensive pond environments. Based on staging of gonad development, GIFT were found to become sexually mature marginally later than the other two strains. At nine months of age, broodstock from each strain were stocked in 5 m² breeding hapas with 5 males and 15 females per hapa and four replicate hapas per strain. Broodstock were sampled for eggs every week and data collected on fecundity and inter-spawning interval for the four strains over the 17 months. Seasonal and environmental variances appear to be the major determinants of egg or fry production with the only strain difference observed being a lower relative fecundity in GIFT. Across all strains, fecundity per female increased over time while fecundity per unit weight of female remained constant. SF and ISIs fluctuated widely between individual fish, and ISIs were even highly variable within individual females making it very difficult to identify trends. Many females spawned very infrequently and means of identifying fecund females could have significant impacts upon hatchery efficiency.

INTRODUCTION

Significant progress in genetic improvement of cultured fish has been made in the last decade, including the implementation of breeding programs for species such as tilapias and carps used extensively in aquaculture in the developing world. There have, in particular, been a number of breeding programs for tilapia, the best known of which is probably the Genetically Improved Farmed Tilapia (GIFT) project initiated by ICLARM (Eknath and Acosta, 1998). The problem of precocious sexual maturation and unwanted reproduction has promoted the widespread use of monosex fish in the industry but also raised a consciousness about sexual maturation and breeding not considered in the culture of most other species.

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Late maturation, and to a lesser extent reduced fecundity, are thus considered desirable traits by growers. However, these are undesirable traits for hatchery producers. Given that tilapia is a low value species, profit margins on seed production can be relatively small. The extra cost of maintaining broodstock for a longer time before initiating seed production and thus maintaining larger fish as broodstock with higher resource requirements (feed and space) and greater difficulty in handling would dissuade many hatcheries from using a late maturing strain unless warranted by the selling price of the seed. This appears to be the case for GIFT tilapia in hatcheries in Thailand where anecdotal information from hatchery managers have indicated that this strain is indeed later maturing than alternative unimproved strains (Turner, pers. comm.). Later maturation has resulted in some hatcheries using only GIFT males as broodstock, crossing those to earlier maturing females from a local strain, thus losing some of the potential benefit of the breeding program which has produced GIFT. The GIFT available in Thailand apparently have not been selected for later maturation, and if later maturation and lower fecundity of this strain are confirmed, these might be considered correlated traits to growth. More rapid growth is considered positive to growers, but negative to hatcheries that carry the responsibility of supplying quality seed to the growers.

Uraiwan (1988) confirmed that a genetic relationship exists between growth rate, age, and size at maturity in tilapia leading to a suggestion that selection can be made more efficient by combining selection for body weight at a particular age with selection for increasing fish growth. Hörstgen-Schwark and Langhölz (1998) argued that the question of whether the selection response for growth rate indicates a beginning of an antagonistic relationship between maturation and body weight still remains unanswered. Longalong et al. (1999) shed some light on this topic in their study on realized heritability of selection for later maturation in the GIFT strain. They observed a highly significant response to selection for early maturation indicating this is a trait with moderate to high heritability. They also observed a correlated response in growth rate with males and females in the early maturing line growing faster than those in the later maturing line, significantly so in the case of the males. Clearly this is an issue that warrants further research.

Materials and Methods

Source of broodstock

GIFT: This stock originates from the Genetically Improved Farmed Tilapia project in the Philippines and was obtained from the Thai National Aquaculture Genetics Research Institute in 2002. This strain is the result of five generations of combined selection for growth on a genetically variable synthetic base population derived from eight separate strain accessions. The GIFT selection program is reported to have resulted in an accumulated genetic gain of 85% in relation to the base population (Eknath and Acosta, 1998). The GIFT tilapia was established as a good strain for aquaculture and has been widely distributed throughout Asia.

Fishgen-select: This stock was obtained directly from the Philippines in 2000 and is a strain developed as a female line for crossing with YY males to produce superior, genetically male tilapia (Mair et al., 1997; Abucay and Mair, in press). This strain was the high line in a breeding program incorporating three generations of intensive within-family divergent selection for growth with rotational mating. Estimates of divergence in growth performance between the high line and low line ranged from 32% to 102% with an average of 60%, equivalent to an estimated response to selection of 30% assuming equal response in high and low lines (Abucay and Mair, in press). This strain is not commercially cultured, but is used in several Asian countries as the female line for the production of GMT.

Philippine-select (IDRC): This stock was also obtained from the Philippines in 2000 and represents the product of 12 generations of within-family selection for 16-week growth (Bolivar and Newkirk, 2000). The stock, known locally as the IDRC strain after the funding agency that supported the initial research, is derived from a base population of locally adapted strains of tilapia available in the Philippines in the late 1980s. Performance evaluations showed that the strain had consistently higher final body weight in tanks, hapas, and ponds than two variants of control lines (random-bred control and mean selected control) and also than unrelated controls including the GIFT strain and a local 'Israel' strain. The reported response to selection was about 3.6% per generation. There were also no significant differences ($P < 0.05$) reported between the final body weight of IDRC and GIFT strains and more recent unpublished data (various sources) has also indicated that the strain has culture performance broadly comparable with GIFT. Subsequent generations of this strain have been distributed for aquaculture, mainly within the Philippines, where it is now known as the FaST strain.

Chitralada: This strain was included to represent a non-selected, but locally adapted control. The Thai-Chitralada strain is derived from a stock of 50 fish, which was introduced to the Royal Chitralada Palace in Thailand in 1965 and originates from Egypt via Japan. This introduction formed the base population for the large majority of tilapias cultured in Thailand up until the early 2000s. This strain has been reproduced intensively at the Asian Institute of Technology (AIT) for at least 10 generations in hapa based seed production systems (Tuan et al., 1999). The strain, though not deliberately selected, has been found to have culture performance at AIT comparable with that of selected strains. For example, in studies conducted in the late 1990s, no significant differences were found in grown and reproductive traits between Chitralada and GIFT (Bhujel, 2000; Yakupitiyage, 1998).

Assessment of sexual maturation

In fish sacrificed for assessment of sexual maturation, gonads were weighed for estimation of gonadosomal indices and the stage of sexual development of the gonads was recorded based on criteria developed by Hörstgen-Schwark and Langhölz (1998) with maturation scored from 1 (no eggs visible) to 6 (spent-with absorption of yolk material) in females, and 1 (testes thread like and colorless) and 7 (milt runs freely under light pressure) in males.

Comparative evaluation of breeding

Fish from the grow-out phases were pooled and maintained in hapas on a maintenance diet of commercial catfish grower pellets up to the age of 180 days at which time they were stocked into hapas for evaluation of breeding. Fish were stocked in 5 m² hapas with 20 fish (5 males: 15 females) per hapa with four replicate hapas per strain. All 16 hapas were placed in the same 200 m² earthen pond.

Eggs were collected from each hapa every seven days according to standard protocols developed at AIT (reviewed by Bhujel, 2000). Each female was tagged with a PIT tag at first spawning and all tag numbers of spawned females were recorded in subsequent collections along with the post-spawning weight, providing full breeding profiles for all spawning females in each hapa. Collected eggs were staged according to their development, weighed, and counted using volumetric estimation. Evaluation of reproduction in the strains is a continuous process and is on-going. This is a preliminary presentation of data collected over 70 weeks representing production from fish in the age range of 6 to 22 months. A problem arose with collection of the data that while most females were tagged (only those that never spawned did not receive a tag), the total number of males and females in a hapa were not counted during the early part of the experiment. Also, some mortality occurred in broodstock over time, which affected the number of breeders remaining in the breeding hapa. These broodstock were replaced after nine months of production, using spare stock that had been retained after harvest at the end of the growth phase and maintained in similar condition to the breeding fish. As a result of the omission of total counts of broodfish it was difficult compare overall productivity of the strains other than by preparing total counts factoring in both fecundity and survival parameters. Variables that could be calculated or estimated from the data included absolute and relative fecundity, spawning frequency, and inter-spawn interval.

The grow-out phase

Broodstock of Chitralada, Fishgen-selected, and Philippine-selected (IDRC) were bred at AIT using standard methods of pooled spawning of broodstock in fine-mesh hapas (Bhujel, 2000) with a minimum of 12 spawning females providing the 4,000 fry representative of each strain. The GIFT fry of the same age (maximum age difference across all fish was two weeks) were obtained from NAGRI. Fry from the different strains were nursed through three stages of nursing at standardized densities, in hapas suspended either in concrete tanks or an earthen pond, with densities reducing through each phase.

After a total of four or six weeks of nursing, fry were stocked, at average weights of 5–6g, into two growth comparison trials under extensive conditions in fertilization only ponds. Emphasis in this trial was not on optimum growth given that the fish were intended for use as broodstock.

In a separate stocking trial, fish were stocked at three per m^2 in three replicate half ponds (100 m^2) making 75 fish per strain per replicate (totaling 6 ponds, each divided into two with a fine mesh screen). Fish were grown for a period of 91 days, with 30 fish being sampled for weight and standard length every 21 days. In the later samplings, 20 fish per half pond were removed for determination of GSI and stage of sexual maturation, thereby reducing the overall stocking density of the ponds. All fish were weighed, measured, and sexed at harvest.

For the second trial in a communally stocked pond, randomly selected six-week-old fish at mean weights of 15–22g were marked by fin clip and coded wire tags (Mair, 2002) and stocked together in a single 200 m^2 earthen pond (600 fish, 150 per strain). Sampling was as for the separately stocked trials and all fish were harvested after 85 days of grow-out.

In both trials fish were not fed throughout but ponds were fertilized with urea at a rate of 28 kg N ha^{-1} $week^{-1}$ and triple super phosphate at a rate of 7 kg P ha^{-1} $week^{-1}$ to stimulate primary productivity.

Data analysis

Growth data from the separately stocked trials was affected by different pond means and sampling bias, for which correction factors were applied (Jere, 2002). Raw and corrected data were compared using ANOVA. Trends in breeding data were subject to preliminary analysis through basic linear correlations and ANOVA for comparisons of parameters between strains.

RESULTS

Assessment of sexual maturation

The results of the staging of sexual maturation of males and females of the four strains at harvest in the separate and communally stocked trials are shown in Figures 1 and 2, respectively. There were no significant differences in the frequency of the different stages of sexual maturation between the strains although an absence of any Stage 5 males or females was noted in GIFT. In the fish reared in separate stocking there were significant differences in GSI in males (Table 1), with GIFT having lower GSI than Fishgen-selected and IDRC. There were no significant differences in GSI among the females in separate stocking. The GSI data from communally stocked fish did not contain sufficient numbers of individuals to warrant analysis.

Figure 1. Stages of sexual maturation of males at harvest for fish from separately stocked (left – aged 119 days) and communally stocked (right – aged 127 days) growth comparisons.

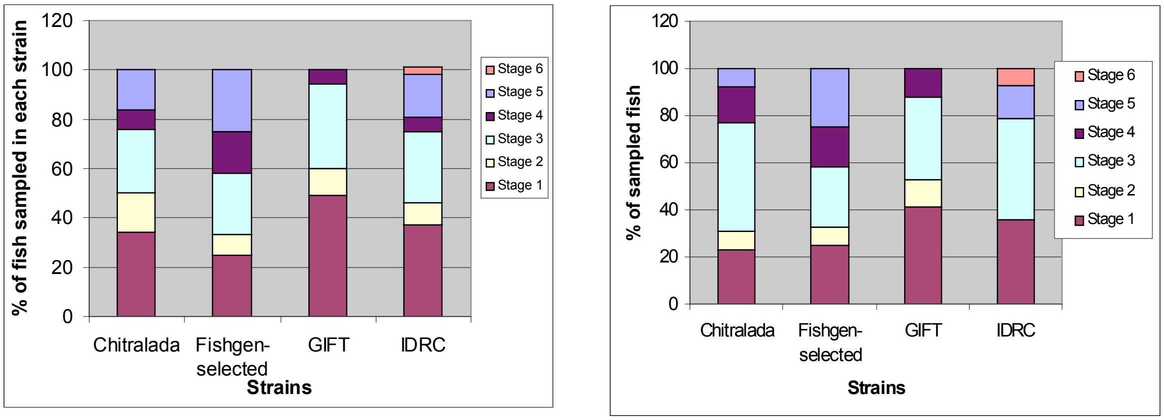

Figure 2. Stages of sexual maturation of females at harvest for fish from separately stocked (left – aged 119 days) and communally stocked (right – aged 127 days) growth comparisons.

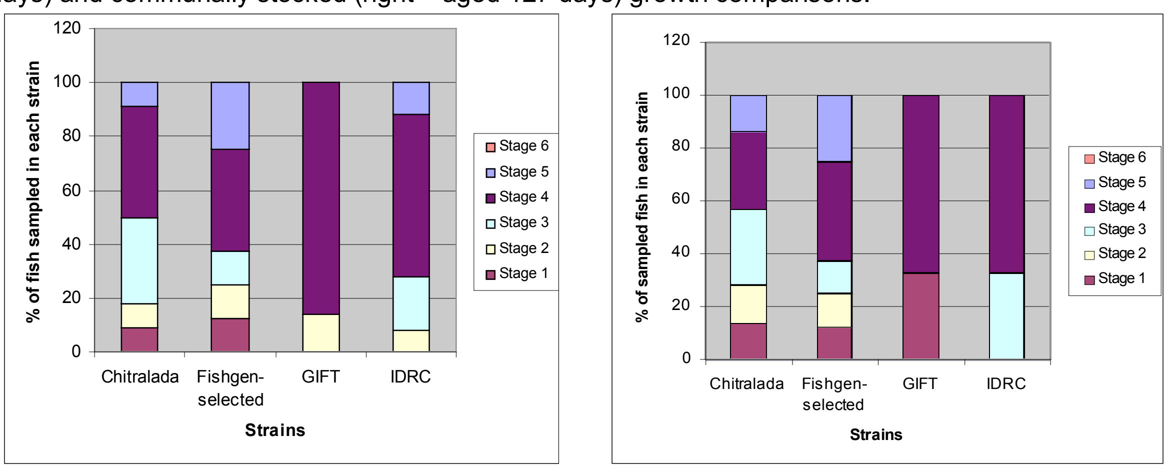

Table 1. GSI (%) for the four strain reared in separate stocking for 91 days (up to an age of 119 days; *n* = 30 per strain)

Strain	Male GSI (%)	Female GSI (%)
Chitralada	0.2618[a,b] ± 0.1462	1.2711 ± 0.1685
Fishgen-selected	0.5801[a] ± 0.0043	0.9079± 0.0207
GIFT	0.1334[b]± 0.0688	1.5736± 0.8478
IDRC	0.4358[a]± 0.1530	1.8965± 0.0497

Comparative evaluation of breeding

Due to the failure to count the total number of fish in the breeding systems during the early part of monitoring, it was not possible to compare overall productivity of the different strains. Comparisons between strains were made of total production (across all replicate hapas) in the eight-week periods immediately after initial stocking (at 180 days old) and after restocking (at 450 days old), which were valid as it was known that insignificant mortality occurred during these periods and thus the number of broodstock were known. In the first of these periods the IDRC strain had a significantly higher mean weekly egg production (7,903) compared to Fishgen-selected (1,399) and Chitralada (1,440), with the production from GIFT being intermediate at 4,821. A similar trend was observed in the second period, although production was much higher as the fish were older and larger. During this period IDRC had significantly higher average total production (18,830) than all the other strains, and GIFT (11,615) also had higher production than Fishgen-selected (4,069) and Chitralada (3,145). Fry production over the 70-week period was highly variable in production, but temporal variation in production seemed to be broadly common to all the strains.

The average number of spawnings per month and the mean egg/fry production per month (Table 2) are both variables that depend on the fecundity of individual females and the number of surviving females, and thus, no meaningful comparison can be made without more detailed information on mortality of broodstock. The GIFT strain had significantly lower absolute and relative fecundity than the other strains. IDRC had the highest ranked absolute fecundity with the locally adapted Chitralada strain having the highest ranked relative fecundity.

Table 2. Comparison of overall production of eggs, by the four strains, over the 70-week evaluation period.

Strain	No of spawnings per month	Mean egg/fry no per month	Absolute fecundity (eggs/fry per female)	Relative fecundity (eggs/fry per g female)
Chitralada	24.38	5014	468^{a}	5.957^{a}
Fishgen-selected	19.23	6830	560^{a}	$5.424^{b,c}$
GIFT	20.77	6898	433^{b}	5.225^{c}
IDRC	18.46	6865	579^{a}	$5.927^{a,b}$

Mean values with different superscript letters in the same column were significantly different among strains.

Investigation of spawning frequency over the 70-week period revealed no significant differences between the strains with average spawning frequencies ranging between five and seven (Figure 3). Investigation of temporal trends in fecundity across all strains combined revealed that absolute fecundity increased with age of the fish, while relative fecundity appeared to remain constant although neither correlation was significant. A similar lack of correlation was observed between relative fecundity and the post-spawn weight of females.

The grow-out phase

There have been a number of studies in recent years on the relative culture performance of various strains of tilapia with varying degrees of scientific rigor and varying results. The growth comparison component of this study is thus not emphasized in this report. In summary, the analysis of data from the growth trial which were analyzed in their raw form and also corrected for pond means and sample bias (from seining) indicated no significant differences between growth of strains in the separate stocking trials despite the fact that the three selected strains were all ranked with higher mean harvest weights than the unimproved Chitralada (Table 3). There were also no significant differences in survival or sex ratio between strains.

Figure 3. Comparison of mean spawning frequency of spawning females in the four strains over the 70-week evaluation period.

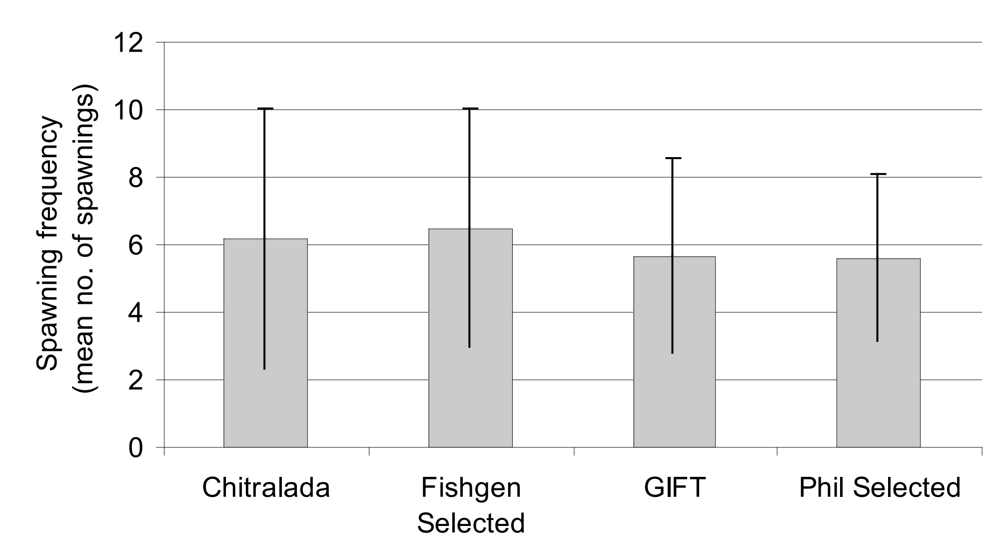

Table 3. Mean weight of communally stocked Nile tilapia, *Oreochromis niloticus* strains corrected for sampling bias and mean length at harvest under communal stocking in 85-days rearing trial.

Parameters	Strain	Mean
Weight (g/fish)	Chitralada	$61.3^{c} \pm 2.3$
	Fishgen-select	$76.3^{a} \pm 2.5$
	GIFT	$72.3^{ab} \pm 2.7$
	IDRC	$65.8^{bc} \pm 2.3$
Sampling corrected weight (g/fish)	Chitralada	$60.7^{c} \pm 2.3$
	Fishgen-select	$71.3^{a} \pm 2.3$
	GIFT	$70.0^{ab} \pm 2.6$
	IDRC	$63.9^{bc} \pm 2.0$
Length (cm/fish)	Chitralada	$14.9^{b} \pm 0.2$
	Fishgen-select	$16.3^{a} \pm 0.2$
	GIFT	$15.8^{a} \pm 0.2$
	IDRC	$15.2^{b} \pm 0.2$

Values are mean ± SE (n = 3). Mean values with different superscript letters in the same column were significantly different among strains.

Similar rankings and growth trends were seen in the comparison of strains under communal stocking but this time growth rates were highly significant in analyses with individual fish as replicates. Fishgen-selected had significantly higher ($P < 0.05$) harvest weight than IDRC and Chitralada, while GIFT had significantly higher harvest weight than Chitralada only. There were no significant differences in sex ratio or survival between the strains.

DISCUSSION

These results shed some light on the debate over the relationship between growth and fecundity in tilapia and the impact of selection for growth on this relationship. The growth trials, although not a major element of this study, appear to confirm superior growth rates of the growth selected strains over the non-selected Chitralada, although these differences were not significant in the replicated trial. Additional growth studies comparing intensive to extensive culture conditions may provide some clues as to which improved strain perform better.

The development of gonads was characterized in the strains at the end of the grow-out phase when the fish were at an age when about 50% of the fish might be expected to be sexually mature (Kronert et al., 1987) despite their relatively small size. The absence of most mature males and females in GIFT provided some indication that this strain is later maturing than the other strains. The differences were not extreme and were not in accord with the GSI data from females in which it might have been expected (in non-spawning fish) that a later maturing strain would have had an overall lower GSI. The timing of sexual maturation and the verification of anecdotal information from hatcheries regarding the late maturation of GIFT females clearly require more substantive examination.

The data set developing from the long-term comparative evaluation of breeding is perhaps unique in that it is tracing spawning patterns of individual fish and may enable us to trace fecundity parameters of tilapia broodstock (focusing on females) throughout their productive life and help determine the optimum ages for using broodstock. There is huge variability in spawning patterns between individual females and over time. Environmental factors and variation between individual fish may be more important factors in hatchery productivity than strain. However, there were some significant differences in fecundity between strains, with GIFT having overall lower fecundity than the other strains, supporting anecdotal evidence supplied by hatcheries. The age-fecundity relationships are in line with expectations for absolute fecundity, although, relative fecundity might have been expected to decline with age, based on findings with other species, admittedly over larger age differences, (Siraj et al., 1983; Ridha and Vera Cruz, 1989). The lack of any relationship between female size (weight) and relative fecundity is also perhaps surprising given the findings of other authors (e.g., Srisakultiew, 1993).

Overall, results from this study do not fully resolve the ambiguity concerning the relationship between size, age, and growth rate in tilapia and the presence or absence of a correlated response to sexual maturation in growth selection programs. The IDRC strain, selected for growth in a within family selection program, would appear to have a positively correlated response in fecundity parameters whereas the response in GIFT would appear to be more of a negative correlation. It is thus difficult to advise hatcheries with regard to expectations for fecundity in growth-selected strains.

One point of far greater importance to hatcheries may be the huge variability in the frequency of spawning by individual females (within or among strains). Many individual females had not spawned at all or had spawned only once in 70 weeks, while others had spawned up to 17 times during this period. Clearly some method for identifying and separating out high and low spawning frequency fish could have a dramatic impact upon hatchery efficiency and profitability far in excess of any fecundity differences that might exist between different strains.

ANTICIPATED BENEFITS

An enhanced understanding of the relationship between fecundity and growth in tilapia is valuable to breeders (in designing appropriate and suitable breeding programs), hatcheries, and growers (in making appropriate stock management decisions). Knowledge of the great variation in fecundity between individual females in a breeding population combined with a system to exploit the fecund fish could have dramatic impacts upon hatchery productivity and efficiency helping to address the issue of constraints in supply of quality seed which exist in numerous parts of the region

ACKNOWLEDGMENTS

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AMAZON AQUACULTURE OUTREACH

Twelfth Work Plan, Sustainable Development and Food Security 1 (12SDF1)
Abstract

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Outreach activities have significantly benefited over 129 producers and their families (256 ponds – 90 ha) in the Peruvian Amazon (Iquitos-Nauta) and 78 producers (23 females, 37 males, and 18 teenagers) and their families in the Colombian Amazon (Leticia), the latter being in its first year of extension activities. Additionally, the two Aquaculture CRSP-funded extensionists have provided aquaculture training to 48 vocational high school students (16 females and 32 males) in the Amazon Basin (Brazil, Colombia, Ecuador, and Peru). One of our extensionists (Pedro Ramirez) from Peru was in an exchange program, initiated in the Eleventh Work Plan, in the Ecuadorian Amazon for one month, training a total of 69 (57 males and 12 females) producers in two basic aquaculture training courses held in El Puyo and Macas. The training courses helped provide technical assistance in aquaculture techniques to local and prospective fish farmers. Fifty-seven individuals representing Ecuador, Brazil, Colombia, Venezuela, and Peru participated in the "4th International Training Course of Prominent Amazonian Aquaculture Species for Students and Professionals," which was held in the National University, Leticia Campus, Colombia, from 21–24 July 2004. Twenty producers and farmers representing Brazil, Colombia, and Peru participated in the "4th International Training Course of Prominent Amazonian Aquaculture Species for Producers," which was held in Leticia, Colombia, from 22–24 July 2004. Eighteen participants representing Brazil and Colombia attended the "1st International Training Course of Ornamental Amazonian Fish Species," which was held in Leticia, Colombia, from 25–27 July 2004. The Amazonian aquaculture website, developed in the Tenth Work Plan, is being maintained. This site is an important tool to communicate the work done by research institutions in the USA, many Amazon basin nations, and elsewhere (over 7,000 hits from 1 August 2004 through 31 July 2005).

UNDERSTANDING THE AGRICULTURAL KNOWLEDGE SYSTEM FOR THE DEVELOPMENT OF AQUACULTURE IN NICARAGUA: ECONOMICS, MARKETS, AND INSTITUTIONS

Twelfth Work Plan, Sustainable Development and Food Security 2 (12SDF2)
Abstract

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The Agricultural Knowledge and Information System for Development (AKISD) is an analytical tool that integrates all the different stakeholders of a system to create knowledge and technology that suits the needs of producers. An Agricultural Knowledge and Information System links people and institutions to promote mutual learning and generate, share, and utilize agriculture-related technology, knowledge, and information. The implementation of this analytical tool requires the holistic analysis of the production system or activity under study and not the isolated analysis of individual producers' units or public and private advocating institutions. For this study, the analysis requires the study of all the different stakeholders on tilapia culture in Nicaragua. The systematic approach is fundamental to combine the different perspectives of stakeholders and disciplines in a holistic process that generates improved technology, policy, markets, and social organization for the increase in productivity of farm-related activities and rural as well as urban development. The study has identified Chinandega and Esteli Departments as areas where clusters of producers and aquaculture infrastructure have developed. Following a training conference in Esteli in November 2005, an increase in the productivity of individual farms affects the level of productivity in the cluster, and clusters affect the level of productivity of other clusters and the overall competitiveness of the Nicaraguan economy. The results of the study should give guidance and direction to the development of the industry and its relation to regional and global markets.

EXPLORING THE POTENTIAL FOR AQUACULTURAL DEVELOPMENT TO PROMOTE FOOD SECURITY AMONG INDIGENOUS PEOPLE IN GUATEMALA

Twelfth Work Plan, Sustainable Development and Food Security 3 (12SDF3)
Abstract

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In Guatemala, the total area of freshwater ponds just exceeds 100 ha, which is less than 10% of the total surface dedicated to shrimp production. Some additional 26 ha produce freshwater prawns for domestic consumption. In 1989, FAO reported that five tilapia species (*Orechromis mossambicus, Tilapia. rendalli, Oreochromis niloticus, Oreochromis aureus,* and *Oreochromis urolepsis hornorum*) have been introduced into the region and stocked in ponds, large water bodies, and even released into open watersheds. The Peace Corps and governmental technical assistance constructed nearly 600 small ponds in recent decades. Most of the ponds are managed on subsistence and semi-commercial levels, but the coffee crisis and a growing market potential have increased interest in tilapia production. Fish are harvested for home consumption, and surpluses are sold in local markets. Women are responsible for the daily management and feeding of these ponds, while the men are primarily responsible for pond construction and harvest. Two case study areas were chosen where several indigenous communities have sustained involvement in tilapia culture for several years. In Comunidad La Bendicion, Pochuta, Chimaltenango, tilapia cultivation is conducted on a communal land, which has an approximate area of 10,000 square meters, confined by a fence. The compound has a single entrance and a mesh door with padlock. As the ponds tend to be close to dwelling areas, the intent is to protect children and prevent theft. The three ponds (two of 4x4 m and one of 15x8 m) are supplied with water from a spring and from a river. The water arrives by gravity through poliductos (flexibile black plastic pipes), which reduces costs since it is not necessary to pump water. The group purchases fingerlings from the experimental station of Amatitlán; this station is managed by the Universidad de San Carlos de Guatemala where sex-reversed and mixed-sex fingerlings are sold. The fish are sold at an average weight of 450 g; most consumers prefer fish of this weight because there can be an individual fish for each family member. The price for which one sells the tilapia is Q 22 kg^{-1} (Q 7.55 = USD$ 1.00). Previously they were selling the tilapia at Q 17.6 kg^{-1}, but most producers could not cover costs at this price. A parallel study is underway in Suchitepequez. The case studies should generate insights into the strategies for advancing aquaculture among Guatemala's poorest peoples in areas with appropriate soil and water resources.

FIRST ANNUAL SUSTAINABLE AQUACULTURE TECHNOLOGY TRANSFER WORKSHOP

Twelfth Work Plan, Sustainable Development and Food Security 4 (12SDF4)
Abstract

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One of the most recent trends in aquaculture production development is the use of recirculating aquaculture systems (RAS). RAS-based aquaculture production is a sustainable form of aquaculture whereby the aquatic environment is all or partially controlled with little or no water exchange with the outside environment. There are many opportunities for RAS production in Mexico. Although considered high-tech and capital intensive compared to extensive pond production techniques, RAS technology is viewed as a must for commercial aquaculture development where strict environmental control is needed at larval and nursery stage production. RAS aquaculture is also applicable for sustainable aquaculture when more conventional forms of aquaculture are not possible, such as in areas with a lack of land resources, poor water (pond) retention, excessive source water contamination, or an inadequate water supply for conventional aquaculture.

This annual workshop will be patterned after the highly successful Cornell University/Freshwater Institute Recirculating Aquaculture Short Course that has been instrumental in educating over 400 aquaculture educators, researchers, and entrepreneurial farmers from around the world on recirculating aquaculture production techniques during the past ten years. The target audience of this workshop will be the researchers and extension personnel of Mexico that are currently involved or intend to be involved in sustainable aquaculture research and production. This workshop will serve to both a) provide technical knowledge to this audience about RAS techniques; and b) link and transfer information from existing ACRSP research currently performed throughout Mexico. In addition, this technology transfer workshop will also strengthen the research and extension ties among the various research universities and institutions of Mexico and provide an additional link to US resources.

NEW PARADIGM IN FARMING OF FRESHWATER PRAWN (*MACROBRACHIUM ROSENBERGII*) WITH CLOSED AND RECYCLE SYSTEMS: THAILAND

Twelfth Work Plan, Production System Design and Integration 1a (12PSD1a)
Abstract

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This study included two parts: an experiment on a water recycling system for giant freshwater prawn (*Macrobrachium rosenbergii*); and a survey of prawn farming systems in Thailand. The experiment was conducted in 15 cement tanks (2 x 2.5 x 1 m) at the Asian Institute of Technology, Thailand, during 5 January to 12 May 2004, to develop closed and recycle systems for culture of giant freshwater prawn. Juvenile prawns were cultured in three systems as three treatments, each in triplicate: A) open system with water exchange; B) closed system with aeration; and C) recycle system, in which water from a prawn tank was circulated through a Nile tilapia (*Oreochromis niloticus*) tank to a water mimosa (*Neptunia oleracea*) tank and back to the prawn tank.

Survival of prawns, ranging from 40.64% to 88.72%, was highest in the closed system, intermediate in the recycle system, and lowest in the open system ($P < 0.05$). Growth of prawns was not significantly different among all three systems ($P > 0.05$), while gross and net yields of prawn were significantly lower in the open system than in closed and recycle systems ($P < 0.05$). Feed conversion ratio (FCR) in the open system was 2.81, which was significantly higher than in the closed (1.67) and recycle (1.78) systems ($P < 0.05$). Prawn recovered 12.02% N and 7.01% P from feed and fertilizer in the open system and 25.26% N and 13.67% P in the closed system. Prawn, tilapia, and water mimosa together recovered 39.55% N and 25.53% P in the recycle system. Economic analyses showed that there were no significant differences in net returns among the three systems.

The socioeconomic and technical survey of 100 prawn farmers was conducted during 1 May to 31 July 2005 in Thailand. Number of surveys conducted within each province was determined in proportion to the average area (rai), production (kg), and number of grow-out farms using 2003 data supplied by the Department of Fisheries, Bangkok, Thailand. Initial analysis shows that the majority of farms (96%) use monoculture systems. The remaining farmers utilized polyculture systems consisting of prawns and white shrimp (*Penaeus vannemai*). The production system utilized by the majority of farmers includes nursing of prawns at post-larval stage and grow-out (90%); others only practice grow-out. External pollution severely impacts 16% of respondents, moderately impacts 46%, and is of no impact to 38%. Further analysis is in progress.

The experiment demonstrated that the closed and recycle systems may be more environmentally friendly and have good profit potential compared to the open system. The survey will provide extensive information about practices currently used in Thailand to produce giant freshwater prawn. By assessing constraints and problems facing farmers, research can be directed to develop economically and environmentally sound production techniques, as well as evaluate the feasibility of implementing new production systems, such as the recycle system, into current farming practices in Thailand.

NEW PARADIGM IN FARMING OF FRESHWATER PRAWN (*MACROBRACHIUM ROSENBERGII*) WITH CLOSED AND RECYCLE SYSTEMS: VIETNAM

Twelfth Work Plan, Production System Design and Integration 1b (12PSD1b)
Abstract

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A survey on giant freshwater prawn (*Macrobrachium rosenbergii*) was conducted in Vietnam during March–April 2005. The survey was to assess the current status of giant freshwater prawn farming, including technical, socioeconomic, and environmental aspects in Vietnam. Forty-seven prawn farmers were randomly selected, among which 15 farmers were located in Co Do district of Can Tho province, 15 farmers in Vinh Thanh district of Can Tho province, and 17 farmers in Thoai Son district of An Giang province. The selected farmers were interviewed using a structured checklist and open-ended type of questionnaire. Data entry and analyses are continuing.

NEW PARADIGM IN FARMING OF FRESHWATER PRAWN (*MACROBRACHIUM ROSENBERGII*) WITH CLOSED AND RECYCLE SYSTEMS: BANGLADESH

Twelfth Work Plan, Production System Design and Integration 1c (12PSD1c)
Abstract

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A survey on giant freshwater prawn (*Macrobrachium rosenbergii*) was conducted in Bangladesh during January–June 2005. The survey was to assess the current status of giant freshwater prawn farming including technical, socioeconomic, and environmental aspects in Bangladesh. One hundred prawn farmers were randomly selected, among which ten farmers were located in Mymensingh district, 30 farmers in Noakhali Sadar district, 30 farmers in Bagerhat Sadar district, and 30 farmers in Fakirhat district. Primary data were collected through face-to-face interviews, using a structured checklist and open-ended type of questionnaire, group discussion, and Participatory Rural Appraisal, while the secondary data were gathered from different governmental and nongovernmental sources. Data entry and analyses are continuing.

OPTIMIZATION OF PHOSPHORUS FERTILIZATION REGIME IN FERTILIZED NILE TILAPIA PONDS WITH SUPPLEMENTAL FEED

Twelfth Work Plan, Production System Design and Integration 2 (12PSD2)
Abstract

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An experiment is being conducted in fifteen 200 m^2 earthen ponds at the Asian Institute of Technology, Thailand. The objectives of the study are to assess effects of different phosphorus fertilization regimes on tilapia production and pond water quality, quantify nutrient budgets, and analyze the cost and return for fish with different phosphorus fertilization regimes and supplemental feed. Ponds were stocked with sex-reversed male Nile tilapia (*Oreochromis niloticus*) of an average size of 95.5 g at a density of 3 fish m^{-2} on 1 September 2005. Urea and triple superphosphate were applied weekly to all ponds at rates of 28 kg N and 7 kg P ha^{-1} wk^{-1} two weeks prior to fish stocking. Supplemental feeding was provided at 50% satiation level. After stocking and feeding fish, phosphorus fertilization was adjusted for different treatments, while nitrogen fertilization was kept unchanged at 28 kg N ha^{-1} wk^{-1} for all ponds. There were five phosphorus fertilization rates as treatments with three replicates each: 0%, 25%, 50%, 75%, and 100% (control) of 7 kg P ha^{-1} wk^{-1}, giving 0, 1.75, 3.50, 5.25 and 7.00 kg P ha^{-1} wk^{-1}, respectively. The experiment will be terminated when tilapia reach 500 g in size.

USE OF RICE STRAW AS A RESOURCE FOR FRESHWATER POND CULTURE

Twelfth Work Plan, Production System Design and Integration 3 (12PSD3)
Abstract

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The objectives of this study are to assess the effects of rice straw on fish production, water quality, plankton, bacterial biofilm, and periphyton; to optimize the loading of rice straw in both Nile tilapia monoculture ponds and carp polyculture ponds; and to compare rice straw and bamboo sticks as substrates in periphyton-based culture systems. This study was comprised of four experiments, conducted in both Bangladesh and Thailand.

Experiment 1 was conducted in 21 outdoor cement tanks of 5 m^2 in surface area at the Asian Institute of Technology during 25 February to 1 April 2005, to investigate physical, chemical, and biological changes of water in the process of the decomposition of rice straw at various loading levels. The experiment used a completely randomized design with seven treatments and three replicates per treatment. The treatments were seven levels of rice straw loading (0; 625; 1,250; 2,500; 5,000; 10,000; and 20,000 kg ha^{-1} on a dry matter basis). Temperature, pH, and dissolved oxygen (DO) were measured daily at dawn, while Secchi Disk visibility was measured daily at 0900 h. Column water samples were taken weekly at 0900–1000 h for the analyses of total alkalinity, total ammonia nitrogen (TAN), nitrite-N, nitrate-N, total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), total volatile solids (TVS), chlorophyll *a*, and tannin. Rice straw samples were taken from each tank at the beginning and end of the experiment to quantify periphyton using Sedgwick-Rafter counts and bacteria using total plate counts. Preliminary analyses showed that DO at dawn, pH, water temperature, and Secchi Disk visibility decreased with increasing loading rates of rice straw ($P < 0.05$), while concentrations of total alkalinity, TP, SRP, TKN, TSS, TVS, and chlorophyll *a* rose with increasing loading rate of rice straw ($P < 0.05$). The analyses of periphyton and bacteria are still going on. The preliminary analyses suggested that the loading rate of 625 kg ha^{-1} could be used in the Experiments 2 and 4 as the base rate.

Experiment 2 will be conducted in eighteen 200 m^2 earthen ponds in a completely randomized design at the Asian Institute of Technology. There were six treatments with three replications each: A) no rice straw mat (control); B) one rice straw mat; C) two rice straw mats; D) three rice straw mats; E) four rice straw mats; and F) rice straw mats covering the slope of dikes. Rice straw mats are prepared by pressing rice straw between bamboo splits. The dimension of rice straw mats is 5 x 1 m. Based on the result of Experiment 1, each mat contains 2.6 kg rice straw (dry weight basis). All ponds were drained completely and limed using agricultural lime at 2,000 kg ha^{-1}. Then the ponds will be filled with water one week later, and fertilized weekly using urea and triple superphosphate at 28 kg N and 7 kg P ha^{-1} $week^{-1}$. Rice straw mats will be suspended vertically in the water column of the treatment ponds according to the design. DO concentrations will be monitored daily at 0600h

in all ponds after placing rice straw mats into treatment ponds. When DO concentrations recover to about 3 mg L^{-1}, sex-reversed Nile tilapia (*Oreochromis niloticus*) fingerlings (about 10 g in size) will be stocked at 2 fish m^{-2}. Then, temperature, pH, and DO will be measured weekly at dawn and late afternoon, while Secchi Disk visibility will be measured weekly at 0900 h. Column water samples will be taken biweekly at 0900–1000 h for the analyses of total alkalinity, TAN, nitrite-N, nitrate-N, TKN, TP, SRP, TSS, TVS, chlorophyll *a*, and tannin. Rice straw samples will be taken from each pond at the beginning, middle, and end of the experiment to quantify periphyton using Sedgwick-Rafter counts and bacteria using total plate counts. At the beginning and end of the experiment, soil, tilapia, and rice straw will be sampled for the analysis of moisture, total nitrogen, and total phosphorus.

Experiment 3 is being conducted in eighteen 40 m^2 earthen ponds in a completely randomized design at the Bangladesh Agricultural University. A long pond (83 x 8.9 m) was drained completely and partitioned by galvanized iron sheets into 18 small ponds of 40 m^2 each. There were six treatments with three replications each: A) no rice straw mat (control); B) one rice straw mat at the middle; C) two rice straw mats at 3 m apart; D) three rice straw mats at 2.25 m apart; E) four rice straw mats at 1.8 m apart; and F) four rice straw mats covering the slope of dikes. Rice straw was pressed between bamboo splits to make mats. Based on the results of Experiment 1, each mat contained 2.6 kg rice straw (dry weight basis). The dimension of rice straw mats was 2 x 1 m for treatments B through E, and 2.5 x 0.9 m and 2 x 0.8 m for treatment F depending on dike size. All ponds were partially filled with water, treated with rotenone to eradiate wild fish, and drained completely one week later. The ponds were then limed using agricultural lime at 250 kg ha^{-1}, filled with water three days later, and fertilized fortnightly at rates 31 kg urea, 16 kg triple superphosphate and 1,250 kg cow dung per hectare. Rice straw mats were placed into the treatment ponds according to design. Two bricks were tied at opposite corners of each mat, and the mats were hung from a bamboo pole placed over the side dikes of the ponds by nylon rope for treatments B through E, while rice straw mats were placed over the slope of pond dike and fixed by bamboo stakes. DO concentrations were monitored at 0600 h daily in all ponds starting from 20 August 2005 when the rice straw mats were placed in the treatment ponds. The concentrations of DO in ponds of treatments D, E, and F dropped quickly to zero a few days after placing rice straw mats in ponds. When DO concentrations recovered to about 3 mg L^{-1}, fingerlings (about 25 g in size) of rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), catla (*Catla catla*), common carp (*Cyprinus carpio*), and silver carp (*Hypophthalmichthys molitrix*) will be stocked at one fish m^{-2} with species ratio of 3:2:2:2:1. Then, temperature, pH, and DO will be measured weekly at dawn and late afternoon, while Secchi Disk visibility will be measured weekly at 0900 h. Column water samples will be taken biweekly at 0900–1000 h for the analyses of total alkalinity, TAN, nitrite-N, nitrate-N, TKN, TP, SRP, TSS, TVS, chlorophyll *a*, and tannin. Rice straw samples will be taken from each pond at the beginning, middle, and end of the experiment to quantify periphyton using Sedgwick-Rafter counts and bacteria using total plate counts. At the beginning and the end of the experiment, soil, carps, and rice straw will be sampled for the analyses of moisture, total nitrogen, and total phosphorus.

Experiment 4 will be done after Experiment 3 is finished to compare the best treatment from Experiment 3 with the developed periphyton-based culture system using bamboo sticks as the substrate. There will be three treatments, each in triplicate: A) no substrate (control); B) the best treatment using rice straw mats as substrate from Experiment 3; and C) periphyton-based culture system using bamboo as substrate.

DEVELOPMENT OF A RECIRCULATING AQUACULTURE SYSTEM MODULE FOR FAMILY AND MULTI-FAMILY USE

Twelfth Work Plan, Production System Design and Integration 4 (12PSD4)
Abstract

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All aquaculture development is constrained by the availability of suitable water resources. Recirculating aquaculture systems (RAS) represent a sustainable approach to aquaculture production. The primary advantage of recirculating aquaculture is the control of the aquatic environment that enables optimal growth conditions of the target species and limits unwanted diseases that can spread in the open environment. The goal of this project is to develop an RAS as part of sustainable food production at the family/multi-family level for rural areas of Mexico. The RAS to achieve the goals of this investigation will be relatively simple yet robust in design to allow for maximum growth with low risk under likely grow-out conditions. The target species of this investigation is tilapia, which is already a popular fish species in Mexico and for which resources to grow tilapia such as fingerlings and feed are readily available.

The objectives of this project are to identify development opportunities within Mexico for small-scale RAS production design, test, and technically evaluate a low-cost RAS and provide recommendations for multiple system implementation. System application research and system design/construction/evaluation will be performed as part of a graduate education program.

INSULIN-LIKE GROWTH FACTOR-1 GENE EXPRESSION AS A GROWTH INDICATOR IN NILE TILAPIA

Twelfth Work Plan, Production System Design and Integration 5 (12PSD5)
Abstract

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IGF-I is a mitogenic polypeptide that is an important regulator of growth in fish. The potential of IGF-I mRNA abundance as an instantaneous growth indicator in Nile tilapia (*Oreochromis niloticus*) was evaluated. Hepatic IGF-I cDNA was isolated and cloned and partially cloned. The partial sequence, having 539 base pairs (bp), was found to code for the signal peptide (44 amino acids [aa]), mature protein (68 aa), and a portion of the E domain (19 aa). The deduced 68 aa sequence for mature IGF-I showed 84–90% and 77–80% sequence identity with fish and mammalian counterparts, respectively, confirming the highly conserved sequence homology among species. The B and A domains were even more highly conserved with respect to the deduced amino acid sequence. Based on the mature IGF-I peptide, a sensitive TaqMan real time qRT-PCR assay for *O. niloticus* was developed for measures of hepatic IGF-I mRNA levels. Hepatic IGF-I mRNA levels were found to be significantly correlated with growth rate of fish reared under different feeding regimes and temperature conditions. These findings suggest that hepatic IGF-I plays a key role in controlling growth of *O. niloticus* and indicates that IGF-I mRNA measures could prove useful to assess current growth rate in this species.

DEVELOPMENT OF NILE TILAPIA FILLETS AS AN EXPORT PRODUCT FOR THE PHILIPPINES

Twelfth Work Plan, Production System Design and Integration 6 (12PSD6)
Abstract

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To process tilapia into fillet products a vital aspect is to have two stages of culture: one is the rearing of fingerlings and the other is the grow-out stage where the fish have to be grown further to reach an individual weight of about 600–800 grams. An experiment was conducted to evaluate the growth performance of Nile tilapia (*Oreochromis niloticus*) in earthen ponds to reach the preferred size for tilapia fillets. Two stocking densities were used as treatments; these were 1 and 2 pcs m^{-2}. Each treatment was replicated three times. Initial average weight of fish stocks was 85.391 gfor Treatment I and 85.052 g for Treatment II. The experiment was done in six 500 m^2 ponds for 120 days. Fish sampling was done once a month to determine the gain in weight of the fish as well as to adjust the amount of feed to be given. The fish were fed with supplemental feeds provided by FEEDMIX Nutrition Specialists three days after stocking at 5%, over time decreasing to 2% of the average body weight of the fish. Pond fertilization was done a week before fish stocking at the rate of 28 kg of N and 5.6 kg of P ha^{-1} $week^{-1}$. Water quality parameters such as dissolved oxygen (DO), water temperature, hydrogen ion concentration (pH), total alkalinity, total ammonia nitrogen (TAN), and Secchi disc visibility were measured once per week. Results showed that Treatment I gave the higher final average weight of 590.168 g and Treatment II resulted in an average weight of 512.994 g. Higher daily weight gain was found in Treatment I with 4.206 g day^{-1} where as Treatment II had 3.566 g day^{-1}. The mean survival rate was 89.1% for Treatment I and 80.8% for Treatment II. In terms of feed conversion ratio (FCR), Treatment I was found lower with 1.6 compared to Treatment II with 1.9. Treatment II gave a higher extrapolated fish yield compared to Treatment I , with mean values of 8,256.4 and 5,250.9 kg ha^{-1}, respectively.

TILAPIA-SHRIMP POLYCULTURE IN NEGROS OCCIDENTAL, PHILIPPINES

Twelfth Work Plan, Production System Design and Integration 7 (12PSD7)
Abstract

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Tilapia-shrimp polyculture has rapidly spread to most of the tropical shrimp farming countries in response to environmental and disease problems. There appears to be several benefits to stocking tilapia in conjunction with lower densities of shrimp. By contributing to a more sustainable aquaculture system, rearing tilapia with penaeid shrimp would benefit the entire industry. More specifically, returning abandoned ponds to a productive system would benefit local populations who have lost employment with the shrimp farms. It would also ameliorate the loss of natural resources that provided nursery areas for fisheries harvest.

The primary focus of the experiment is to work with one or two farms in the Philippines that have begun commercial-scale polyculture of tilapia and shrimp. One farm is on Negros and the other is in Mindanao. We will test three stocking plans for a polyculture system by conducting tilapia-shrimp polyculture trials in active ponds at one of these farms. Trials will compare three polyculture systems: sequential with tilapia in supply pond; simultaneous with tilapia in cages in ponds; and simultaneous with tilapia loose in ponds with shrimp. Water quality data will be collected to determine if culture of tilapia in conjunction with penaeid shrimp increases the number of green algae cells per ml of culture water. We will also attempt to determine if the concentrations of yellow and green fluorescing bacteria are significantly different between treatments.

Central Luzon State University has been coordinating with both farms to place a student on-site. The student will determine the exact polyculture system in use through a survey of stocking densities, ages and size at stocking, and size and construction of cages. Our plan is to replicate the stocking densities in the Philippines and Mexico. Stocking of the experiments should occur in November, as well as monitoring of on-going farm-based trials.

TESTING THREE STYLES OF TILAPIA-SHRIMP POLYCULTURE IN TABASCO, MEXICO

Twelfth Work Plan, Production System Design and Integration 8 (12PSD8)
Abstract

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Tilapia-shrimp polyculture has rapidly spread to most of the tropical shrimp farming countries in response to environmental and disease problems. There appear to be several benefits to stocking tilapia in conjunction with lower densities of shrimp. By contributing to a more sustainable aquaculture system, rearing tilapia with penaeid shrimp would benefit the entire industry. More specifically, returning abandoned ponds to a productive system would benefit local populations who have lost employment with the shrimp farms. It would also ameliorate the loss of natural resources that provided nursery areas for fisheries harvest.

The primary focus of the experiment is to test three stocking plans for a polyculture system by conducting tilapia-shrimp polyculture trials in abandoned shrimp ponds in Tabasco, Mexico. Trials will compare three polyculture systems: sequential with tilapia in supply pond; simultaneous with tilapia in cages in ponds; and simultaneous with tilapia loose in ponds with shrimp. Water quality data will be collected to determine if culture of tilapia in conjunction with penaeid shrimp increases the number of green algae cells per ml of culture water. We will also attempt to determine if the concentrations of yellow and green fluorescing bacteria are significantly different between treatments.

In July 2005, one of the students from Tabasco, Mexico (Rafael Garcia) came to attend the Shrimp Pathology short course at the University of Arizona. We are also working on Rafael's admission to the University of Arizona for January 2006.

The tilapia-shrimp experiments will be conducted from November 2005 to May 2006 at the "Centro Piscícola Puerto Ceiba" in Paríso, Tabasco, Mexico. Refurbishment of the ponds has begun, and stocking should take place in November.

CONTROLLED REPRODUCTION OF AN IMPORTANT INDIGENOUS SPECIES, (*SPINIBARBUS DENTICULATUS*) IN SOUTHEAST ASIA

Eleventh Work Plan, Indigenous Species Development 2 (11ISDR2)
Final Report

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ABSTRACT

Preliminary studies were conducted to understand basic reproductive parameters of the indigenous carp, *Spinibarbus denticulatus* as a prelude to more specific research studies and subsequent development of hatchery technology. The study objectives were to: 1) understand the seasonal pattern of gonad development, sexual maturation, and various reproductive parameters; and 2) induce this species to spawn in captivity using natural and artificial methods.

The study was carried out on sub-adult and adult fish. Gonad and egg development were assessed over a 12-month period. Annual rings on fish scales were found to be a reliable measure of age. In a population including males and females of similar age, males were generally smaller (2.54 ± 0.34 kg) than females (3.46 ± 0.45 kg). The age at sexual maturation of a natural stock was earlier for males (4 years) than females (5 or older). The gonadosomic index revealed two peaks, April and October. Further examination of the ovaries and eggs during January, February, and March suggested that eggs were developing at various stages. During January, the eggs in the ovary of mature females were uniformly small (0.7 ± 0.1 mm diameter.). Two distinct egg groups (0.7 ± 0.1 mm, 36%; and 1.0 ± 0.2 mm, 54%) were observed in February. Three distinct size groups were observed during March (1.1 ± 0.03 mm, 1.6 ± 0.01 mm and 2.1 ± 0.03 mm). The proportion of large eggs (55%) was higher compared to mid (26%) and small eggs (19%) during the near-peak spawning month. The average number of eggs in the ovary of a female (3.1 ± 0.4 kg) was 31,041 (range: 12,632 to 45,359). Males synchronized milt production with egg maturation and ovulation under pond conditions. Milt flowed out readily from males during the spawning season. Sperm characteristics were similar to those of most teleosts. The mean sperm concentration was 8.42 ± 0.36 million cells per ml with only a small amount (3.3 ± 0.2 ml) of total expressible milt per male. However, when induced with LHRHa (10 μg kg^{-1}) the milt production increased to 6.2 ± 0.5 ml without an increase in the total number of sperm cells. While this new species for aquaculture shows potential for mass production of seed, low fecundity and late puberty could present obstacles to artificial seed production.

Induced breeding trials indicated that natural induction methods (rain simulation, decreased/increased water depth and flow) did not stimulate mature females to spawn in ponds. A series of locally available hormones (e.g., HCG, LHRHa+Domperidone, CPE), singly or in combinations, was used to induce females to ovulate. Administration of LHRHa, CPE, and HCG were effective in inducing ovulation for *S. denticulatus*. However, LHRHa or CPE induced ovulation more consistently compared to HCG.

Fertilization rate and hatch rates were also higher in LHRHa or CPE than HCG induced group. Individual females released between 4.2 and 9.4 x 10^3 eggs when stripped, and egg numbers were correlated with BW of the female. Simultaneous injection of LHRHa and domperidone was

required to achieve high success in induced spawning of *S. denticulatus.* Furthermore, no clear advantages were evident to the other hormone combination strategies.

INTRODUCTION

Chinese carps, Indian major carps and tilapias make up over 90% of the freshwater species cultured. Over 95% of these come from Asia (FAO, 2003a), and most are exotic species in Southeast Asia (Liste and Chevey, 1932). Although the culture of introduced species is profitable, exotics have been implicated in either displacement of indigenous species or introgression with local species (Ogutu-Ohwayo and Hecky, 1991; De Long and Van Zon, 1993; NaNakorn et al., 1999). Additionally, exotic species are more susceptible to local diseases, for example grass carp is prone to red spot disease (Kim et al., 1999). Grass carp, a primary cultured species for the rural poor and a major source of animal protein in their diet, has been so severely affected by this pathogen that many poor farmers of North Vietnam have abandoned its culture (Bart, 2000). There is a need to identify an alternative species, preferably indigenous, to grass carp, which can be fed readily available low-cost grass.

Southeast Asia has one of the highest diversities of freshwater fish species in the world (FAO, 2003b). Unfortunately, comparatively few species from this region are widely cultured, partly due to the lack of sufficient knowledge of their reproductive biology. The carp, *Spinibarbus denticulatus* (Oshima, 1926) has significant potential to become a more widely farmed species, particularly for the low-input system relevant for developing countries, if hatchery produced seed is available. With the local name 'ca bong', *S. denticulatus* is indigenous to North Vietnam with a distribution from upstream to the middle reaches of the Red, Lo, and Gam river systems. There is distinct cold and warm seasonal variation in water temperature ranging from 9 to 16ºC during winter and 25 to 30ºC during summer. This species comprised 25 to 30% to the total wild fish capture in the Lo and Gam river systems in the past, and 20 to 30% of that in the Ba Be reservoir (Hao, 1993). *S. denticulatus* belongs to the sub-family, Barbinae of the Cyprinidae family. The largest *S. denticulatus* recorded was 30.0 kg (Dau and Le, 1971). It is a macrophagous herbivore with a diet similar to that of the grass carp (Bau, 1998). No studies on its life history, or descriptions of its habitat have been published to date.

An attractive feature of this species is its resistance to some local pathogens such as red spot disease, even when raised in the same cage with infected grass carp (personal communication, Mr. Pham Bau, Research Institute for Aquaculture No. I, Vietnam). Spawning is thought to take place during the spring and fall months. Natural stocks are declining because of increasing fishing pressure, habitat destruction through construction of hydropower dams and improper capture practices using dynamite and poison. There has been no publication describing even the most fundamental biology of this species. A thorough study would provide basic information on reproductive biology prior to producing seed for stocking. Therefore, in this study we first carried out preliminary investigation to understand the basic reproduction biology of the species and then attempted to induce spawn using natural and artificial methods.

MATERIALS AND METHODS

Reproductive biology of *S. denticulatus*

Male and female *S. denticulatus* (n = 270) ranging from three to seven years of age were acquired from fish cages in Ha Giang and Tuyen Quang provinces, transported to Me Linh Research Station, Vinh Phuc province and held in nine earthen ponds (300 m^2) for the study. Fish were fed a combination of grass and rice sprouts *ad libitum*. Water quality (pH, dissolved oxygen, total ammonia and nitrite) was monitored weekly throughout the study period.
To assess gonadal development and maturation, 10 fish (five-years or older) were sacrificed monthly (December 2001 to November 2002) and fish weight and gonad weight measured to the nearest 0.01 g. To determine age at sexual maturation 3- (n = 8), 4- (n = 10), and 5-year-old females

(n = 19) were harvested in April. All fish in the three age groups were dissected to assess the condition of the gonads.

Age was determined by counting scale annual rings. Scales were removed from above and below the lateral line, washed, and then examined under a microscope. Scale readings were crosschecked with farmer information on the size and date of stocking. Monthly observations of scales from a male and a female fish over the 12-month period were also made to observe the appearance of the dark ring. Visual observations of experimental animals were made during the peak and off spawning seasons for color changes and other sexual dimorphic characteristics.

Nine females were dissected each month and their ovaries were removed to assess fecundity. The number of eggs in the ovary was estimated by first removing all eggs from the connective tissue of the ovary, and by sampling approximately 15 g of mixed eggs from each female. From the 15 g of mixed eggs, 50 oocytes were randomly removed, and each egg was measured to the nearest 0.01 mm using the micrometer of a compound microscope. The diameter of various size eggs was enumerated starting from January (prior to the spawning period), and ovarian oocyte size-frequency distribution was determined over a three-month period (January through March). Eggs belonging to the same size group were separated and classified into three categories, and monthly change in size composition was determined.

Male fish (four to seven years of age) were removed from the water, dried, and gentle abdominal pressure was applied, using a thumb and an index finger to remove sperm. The pressure was applied starting below the pectoral fins and moving down towards the genital pore. This process was repeated until sperm stopped flowing. Total expressible milt was pooled from an individual male and drawn into a 5.0 ml syringe to assess total volume. Sperm motility was assessed under a microscope by adding a droplet of distilled water on the freshly stripped sperm. Two stages of motility, progressive (vigorous movement) and vibration (movement *in loco*) were observed. Sperm concentration (spermatozoa mL^{-1} of milt) was estimated using Neubaur's counting chamber following Vutiphandchai & Zohar (1999).

To increase the amount of expressible sperm, mature males (n = 13) of similar size (2.6 ± 0.3 kg) were harvested and six were injected with LHRHa at 10 $\mu g\ kg^{-1}$, while the other seven were injected with 0.9% saline solution as blank controls. Males were stripped after 6 h of injection and volume measured using a 10.0 ml standard syringe. The number of sperm per ml of milt was estimated using Neubaur's counting chamber.

Induced breeding

Male and female *S. denticulatus* ranging from three to seven years of age were acquired from fish cages in Ha Giang and Tuyen Quang provinces, transported to Me Linh Research Station, Vinh Phuc province and held in earthen ponds (300 m^2) for the study. A total of 30 fish (20 females and 10 males) were stocked in each pond (1.4 m deep) and were fed rice sprouts at 3% of BWD for 6 days a week. A total of 239 females (2.81 ± 0.71 kg BW) and 90 males (2.28 ± 0.39 kg BW) were used for induced breeding trials during the reproductive season of 2002 to 2005. Pond water was exchanged over three-day intervals and water quality (temperature, pH and DO) was monitored weekly during the experiment.

Induced spawning experiments were conducted using a hormone that was commercially available in North Vietnam. Mature brood fish were selected and kept in circular tanks under constant water sprinkling to simulate rain. Selected females displayed enlarged abdomens with swollen and pink genital papilla while males released milt readily with a slight pressure on the abdomen. Common carp pituitary extract (CPE) (two mg $unit^{-1}$ preserved in the acetone solution), luteinizing hormone-releasing hormone analogue (LHRHa), domperidone maleate (Motilium–M), and human chorionic gonadotrophin (HCG) were used to induce females. HCG doses of 3000–5000 IU kg^{-1}, pituitary gland doses of 20 to 40 mg kg^{-1}, and LHRHa doses of 30 to 50 $\mu g\ kg^{-1}$ combined with or without domperidone were used for each hormone dose. The hormones were injected intraperitoneally with two doses including priming and resolving doses administrated eight h apart. The males were given a single dose at the same rate. Injection volume was maintained at 1 ml kg^{-1} BW. A group of nine fish were injected with 0.9% saline solution as a control. Female and male fish were kept separately.

Females were stripped and eggs were fertilized using dry methods. The weight of freshly stripped ova was determined for 190 females for an estimation of fecundity. The excess milt was removed several times after fertilization, and then the fertilized eggs were placed in incubators. Water temperature was recorded at 1-hour intervals over the embryonic development for estimation of degree-hours (time interval between resolving dose and stripping × water temperature). The fertilization rate of eggs was determined after blastopore closure from a sample of 30 eggs collected from the incubator. Ovulation time was recorded, and fertilization and hatch rates were estimated. Fertilized eggs were sampled from the incubator in 10-minute intervals, placed in a Petri dish, and observed under the microscope. The fertilization rate was expressed as the percentage of fertilized eggs from the total number of eggs spawned, and hatch rate was expressed as the percentage of larvae hatched from the total number of fertilized eggs.

Data were analyzed with a one-way ANOVA, and differences were considered significant at α = 0.05. Significant differences between treatment means were compared using the Duncan Multiple Range Test (Pratapa, 2000). Data calculated as percents were arcsine transformed before analysis. A correlation curve of fecundity and coelomic fluid content related to weight was fitted. Statistical analysis was performed using SPSS 11.0 software (SPSS, Chicago, USA).

RESULTS

Reproductive biology of *S. denticulatus*

During the peak-spawning season, mature bi-lobular ovaries appeared turgid and brownish in color. Prior to spawning, ovaries made up over 60% of the abdominal cavity. Similarly, the mature bi-lobular testis appeared pink in color and comprised a smaller portion (< 10%) of the abdominal cavity.

A bi-modal gonadosomatic index (GSI) was apparent in females observed over a 12-month period, with a major spike occurring in April (3.65 ± 0.7) and a minor spike (2.64 ± 0.2) in October (Figure 1). The largest ovary sampled in April was 130 g, 5.0 GSI. The lowest gonadal weight was found in December (19 g, 0.54 GSI) followed by slightly larger one in June (28 g, 0.85 GSI). During January, February, and March an increased proportion of the maturing large oocytes sampled paralleled an increasing GSI.

A similar bi-modal GSI was observed in males (Figure 1), but of a lower magnitude compared to the females. A major peak occurred in April (1.37 ± 0.2) and a minor peak (1.36 ± 0.1) in October. The largest testis sampled in April was 40.0 g with a 1.4 GSI. The lowest gonadal weight was found in December (14.0 g, 0.8 GSI) followed by one in June (16.0 g, 0.6 GSI).

Oocyte size assessment in the ovary revealed that there were distinct size classes of developing eggs rather than a continuous size distribution (Figure 2). The size of oocytes during the early spawning season (January) was found in a single class, 0.7 mm (0.6–0.8mm). A second size-class was foundfor February, 1.0mm (0.9–1.2mm). Approximately 36% of the eggs were small while the remainder (54%) was larger during this sampling period. In March, three class sizes were observed, 1.1 (0.8–1.4mm), 1.6 (1.4–1.8mm), and 2.1 (1.9–2.4mm), with relative proportions of 18.7, 26.4 and 54.9%, respectively. A progressive color change from opaque white to translucent yellow was observed during the early February to March sampling periods. Eggs in the smallest size class were pale yellow while progressively larger eggs were dark-yellow to light brown in color.

Figure 1. Monthly changes in gonadosomatic index (gonad weight/body weight x 100) of male and female *S. denticulatus* (>5 years old) over a 12-month period. Error bars indicate SD.

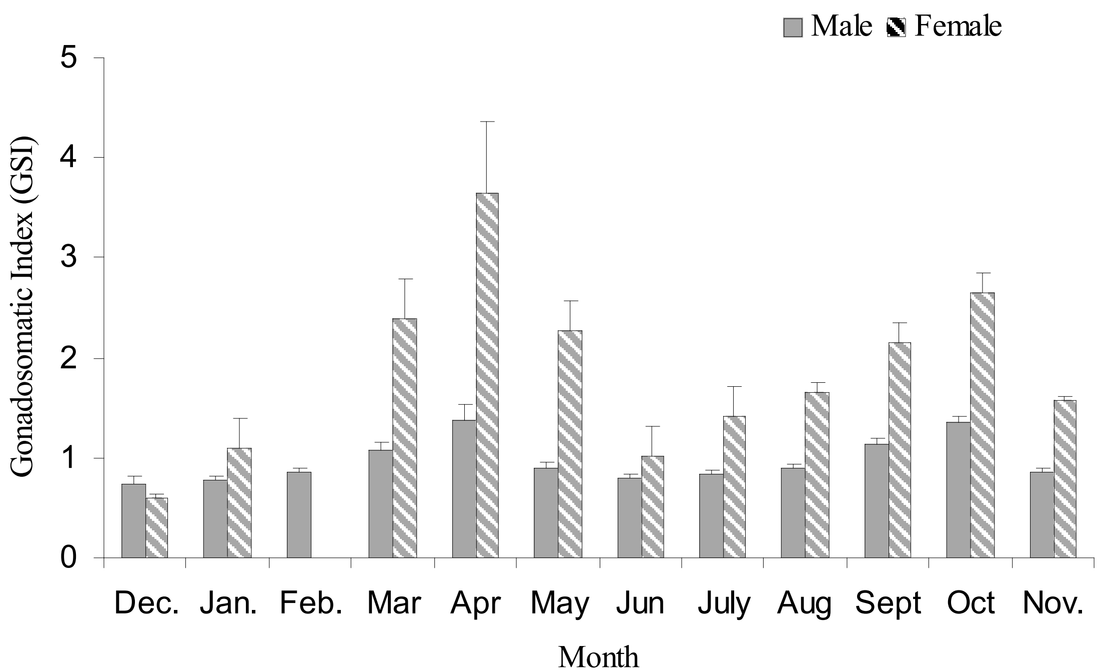
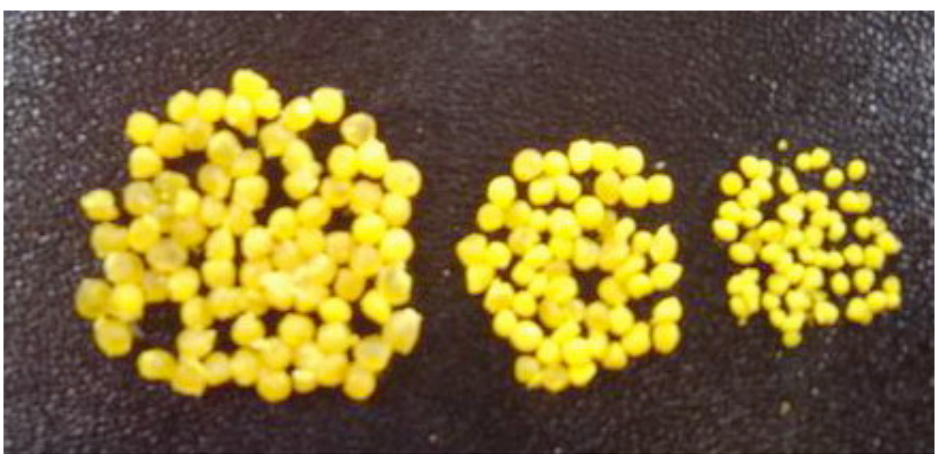


Figure 2. Three class size eggs: 1.1 (0.8–1.4 mm), 1.6 (1.4–1.8 mm), and 2.1 (1.9–2.4 mm) in the ovary of a 5-year-old female examined in March–April.



There was a wide range of egg numbers among females sampled (13,000–45,000 eggs per fish). The number of eggs per kg of female ranged from 6,000 to 14,000, with a mean of 9,873. However, there was no correlation between weight and fecundity among the eight females (3.1 ± 0.4 kg) examined.

Microscopic observation of sperm cells (100x–oil emersion) indicated that they were similar to those of other teleosts with a head, mid-piece, and a single tail. While progressive or vigorous motility duration was only 1.9 ± 0.3 min, total motility (progressive motility and vibration *in loco*) was longer, 2.7 ± 0.3 min. Fish injected with hormones expressed a considerably higher volume of milt (6.2 ± 0.5) compared with those injected with saline only (3.3 ± 0.2). The density of sperm in fish without hormonal induction (16×10^6 ml^{-1}) was double that of hormone injected males (8.4×10^6 ml^{-1})

indicating that the total sperm number was unchanged by hormone treatment. While sperm remained motile over a 5-hour period (sampled every 30 min from the time of stripping), there was progressive decline in the duration of motility after two hours.

Although males and females of age three to seven years were held in nine ponds for a 12-month period, neither mating behavior nor recruitment was observed. A clear and distinctive annual ring was observed on scales of mature fish (Figure 3). The scale dark rings were irregular in shape with varying distances between the rings and between stocks. While most rings were complete circles, a few were only partly complete. The monthly observation of rings for males and females did not differ. Initiation of the dark ring was first observed in January, although temperatures started to decline by the end of November.

Figure 3. Scales of *Spinibarbus denticulatus* removed from below the lateral line of three females of *S. denticulatus* of age four, five, and six (left to right, respectively). Dark rings represent the annual growth.

S. denticulatus males tended to be smaller (2.3 ± 0.2 kg) than females (3.3 ± 0.4 kg, Figure 4) in the five-, six-, and seven-year age class. It was difficult to ascertain sexual dimorphism before maturation or during the non-spawning season. However, during the spawning season, males tended to be more colorful with an iridescent green appearance. Males possessed a rough texture (pearl organs) along the exterior of the operculum running below the eyes towards the mouth during the peak spawning period. One of the most obvious signs of a mature male during the spawning season was the release of milt. Milt flowed readily out of the genital pore with slight pressure to the abdomen. During the spawning period, mature females had an enlarged abdomen. Both spawning females and males became more colorful with the females slightly lighter in color than males. Unlike the genital papilla, which is often swollen and pink during the spawning season in most fish, the female genital opening was covered with a white fleshy protrusion. Males appeared to have only a simple opening without a protrusion.

The mean weight of a five-year-old fish's ovary was significantly higher (81.4 ± 34.8 g) than in three- (14.9 ± 1.1 g) or four-year-old (24.7 ± 3.4 g) females (Table 1). Large variation in gonad size was observed between different age groups with approximately a two-fold increase in four-than in three-year-old, but six times higher in the five-year-old group. The gonadosomatic index of five-year-old fish was also higher (2.8 ± 1.2) than those of three- (1.1 ± 0.1) and four-year-old (1.2 ± 1.0) females. No observable difference was found between the GSI of three- and four-year old fish. The mean weight of females varied with age, where three-, four-, and five-year-old females were 1.4 ± 0.1, 2.1 ± 0.1, and 2.9 ± 0.5 kg, respectively.

Figure 4. Mean weight of females (n = 24) and males (n = 19) at age of five-, six-, and seven-years over a 12-month culture. Error bars represent SD.

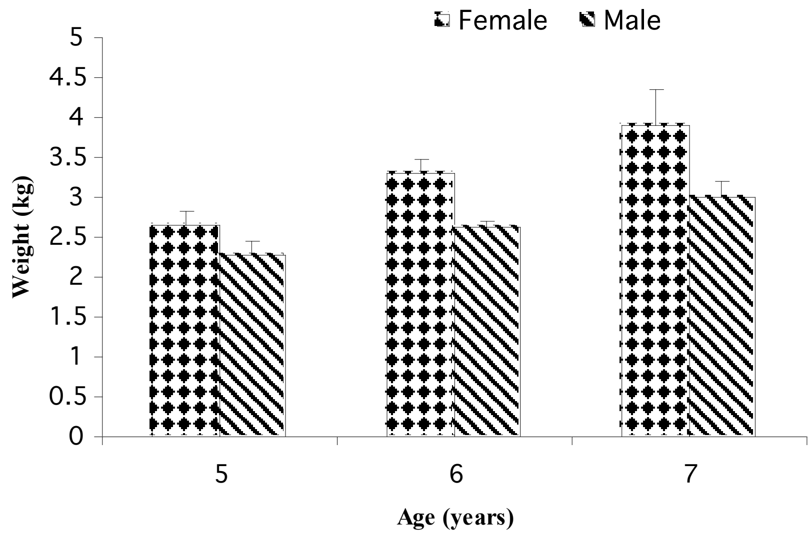


Table 1. Mean (± SD) gonad weight, body weight and gondosomatic index of three-, four-, and five-year old females during April (the peak-spawning period). Different letters in a row indicate significant difference among values (P < 0.05).

Parameters	**Age of female (years)**		
	Three	Four	Five
Gonad weight (g)	16.7 ± 3.8^{b}	24.7 ± 3.4^{b}	81.4 ± 35.8^{a}
Weight of female (kg)	1.4 ± 0.1^{c}	2.1 ± 0.1^{b}	2.9 ± 0.5^{a}
Gonadosomic Index (%)	1.1 ± 0.1^{b}	1.2 ± 1.0^{b}	2.8 ± 1.2^{a}
Number of individuals	8	10	19

Induced breeding

Ovulation was observed in fish injected with LHRHa at a dosage of 40 or 50 μg kg^{-1}, but fish did not ovulate when injected with 30 μg LHRHa kg^{-1} (Table 2). LHRHa at 40 or 50 μg kg^{-1} BW resulted in 25% and 50% ovulation, respectively, whereas addition of domperidone (10 mg kg^{-1}) to the LHRHa injection (40 and 50 μg kg^{-1}) resulted in 100% ovulation and also a reduced latency period. Mean fertilization and hatch rates were high for induced females injected with LHRHa, and there were no significant differences in fertilization and hatch rates between the dosages of LHRHa injected.

Carp pituitary extract (CPE) of 30 or 40 mg kg^{-1} induced female to spawn, although 20 mg kg^{-1} failed to induce ovulation. Mean degree-hours for induced spawning with CPE was 489 and 487 at 30 and 40 mg kg^{-1}, respectively. This was much lower than the degree hour (622–724) observed in the case of LHRHa. Fertilization and hatch rates were not different between the dosages of CPE-treated females and were similar to the rates obtained with LHRHa injection.

Table 2. Results of induced spawning of pond raised *Spinibarbus denticulatus* under various hormone treatments.

Treatments	Stripping response (%)[1]	Mean weight (kg)	Degree hours[2]	Eggs collected (no x 10^3)	Fertilization rate (%)	Hatch rate (%)	Coelomic fluid (g)	Coelomic fluid (%)[3]
SINGLE HORMONE STIMULATION								
LHRHa 30 μg kg^{-1**}	0: 4 (0%)	3.1 ± 0.2	-	-	-	-		-
LHRHa 40 μg kg^{-1**}	1: 4 (25%)	3.1 ± 0.2	724	7.4	93.3	92.9	33.3	31.0
LHRHa 50 μg kg^{-1**}	2: 4 (50%)	3.0 ± 0.4	724	8.5 ± 0.39	93.3 ± 4.7	92.8 ± 0.4	34.0 ± 2.5	28.5 ± 0.6
LHRHa 40 μg kg^{-1***}	6: 6 (100%)	2.7 ± 0.2	623	7.2 ± 0.38	90 ± 4.7	89.5 ± 4.4	29.5 ± 4.2	29.0 ± 2.3
LHRHa 50 μg kg^{-1***}	9: 9 (100%)	3.0 ± 0.1	622	8.0 ± 0.88	91.9 ± 2.9	88.2 ± 4.8	30.9 ± 2.9	28.0 ± 2.7
Pituitary gland 20 mg kg^{-1}	0: 3 (0%)	3.3 ± 0.5	-	-	-	-		-
Pituitary gland 30 mg kg^{-1}	13: 14 (93%)	3.2 ± 0.5	489	9.4 ± 2.3	89.7 ± 4.6	88.5 ± 4.9	21.3 ± 5.9	18.4 ± 2.1
Pituitary gland 40 mg kg^{-1}	15: 15 (100%)	3.1 ± 0.4	487	9.3 ± 2.1	92.0 ± 3.7	90.5 ± 3.8	20.7 ± 4.3	18.3 ± 1.8
HCG 3000 IU kg^{-1}	0: 3 (0%)	3.2 ± 0.7	-	-	-	-		-
HCG 4000 IU kg^{-1}	1: 3 (33%)	3.2 ± 1.0	720	9.9	83.3	84.0	42.7	29.9
HCG 5000 IU kg^{-1}	1: 3 (33%)	2.4 ± 0.3	720	6.8	86.7	80.8	27.8	28.9
COMBINED HORMONE STIMULATION								
LHRHa30 μg + PG 6mg kg^{-1***}	0: 5 (0%)	3.2 ±0 .1	-	-	-	-		-
LHRHa35 μg + PG 6mg kg^{-1***}	4: 6 (67%)	2.9 ± 0.2	630	6.2 ± 1.6	78.3 ± 4.3	79.9 ± 3.3	25.5 ± 6.0	29.4 ± 1.9
LHRHa40 μg + PG 6mg kg^{-1***}	57: 59 (97%)	3.2 ± 0.6	623	7.6 ± 2.2	90.3 ± 4.6	87.5 ± 5.6	30.9 ± 8.9	28.9 ± 1.9
LHRHa50 μg + PG 6mg kg^{-1***}	57: 61 (93%)	3.2 ± 0.5	622	8.4 ± 2.4	89.8 ± 3.9	90.6 ± 4.5	34.5 ± 10.3	29.1 ± 1.8
PG 6mg +HCG 3000 IU kg^{-1}	0: 4 (0%)	3.0 ± 0.4	-	-	-	-		-
PG 6mg +HCG 3500 IU kg^{-1}	4: 7 (57%)	3.4 ± 0.3	720	9.3 ± 0.39	81.7 ± 4.3	83.6 ± 3.5	39.2 ± 0.5	29.8 ± 1.0
PG 6mg +HCG 4000 IU kg^{-1}	16: 16 (100%)	3.1 ± 0.8	678	7.1 ± 2.8	90.0 ± 3.2	87.5 ± 5.2	29.6 ± 11.4	29.1 ± 1.9
PG 6mg+ HCG 5000 IU kg^{-1}	4: 4 (100%)	2.4 ± 0.2	672	4.5 ± 0.79	93.3 ± 2.7	91.1 ± 1.9	18.4 ± 3.4	28.3 ± 0.7
SALINE INJECTION (0.9% NaCl)	0: 9 (0%)	3.0 ± 0.5	-	-	-	-		-

[1]Number of fish spawned: total number of hormone treated fish
[2]Mean temperature (measure hourly) multiplied with time interval between resolving dose and stripping time
[3] (Coelomic fluid weight / total weight of oocyte mass) X 100
**without Domperidone (DOM)
*** with DOM of 10 mg tablet kg^{-1}

Ovulation was not induced with HCG at 3000 IU kg^{-1}, though HCG injection of 4000 and 5000 IU kg^{-1} only succeeded in inducing ovulation in only one female out of the three injected. Fertilization and hatch rates obtained with HCG induction were lower than the rates obtained with LHRHa and CPE injection.

Combining LHRHa and CPE at a dose of LHRHa 30 $\mu g\ kg^{-1}$ + CPE 6 mg kg^{-1} did not result in successful spawning. The minimum successful dosage of LHRHa was 35 $\mu g\ kg^{-1}$ when combined with CPE (6 mg kg^{-1}), but that dosage resulted in a significantly lower stripping response, fertilization rate, and hatch rate than those observed with LHRHa at higher dosages (40 or 50 $\mu g\ kg^{-1}$), given either as single or in combination with CPE. Combining LHRHa at dosage of 40 or 50 $\mu g\ kg^{-1}$ with CPE (6 mg kg^{-1}) resulted in successful spawning, and the results, in terms of stripping response, fertilization rate, and hatch rate, were comparable to those obtained with LHRHa alone. With HCG used in combination with CPE (6 mg kg^{-1}), the minimum effective dosage of HCG to induce ovulation was 3500 IU kg^{-1} with an ovulation response of 57%. Combining CPE (6 mg kg^{-1}) with HCG at 4000 and 5000 IU kg^{-1} also resulted in a significant increase in ovulation response, fertilization and hatch rates as compared to the HCG injection alone. In addition, combined injection of HCG and CPE resulted in fewer degree-hours to ovulation than the treatment with only HCG stimulation.

Overall, fertilization rates observed in this study with different hormone stimulation were high (> 90%). Mean hatch rates obtained in this study varied between 80 to 93% and generally tended to increase with higher fertilization rate (Table 2). In this study, none of the fish given saline injection ovulated (Table 2). Similarly, fish injected with LHRH-a (30 $\mu g\ kg^{-1}$), PG (20 mg kg^{-1}), HCG (3000 IU kg^{-1}), LHRHa (30 $\mu g\ kg^{-1}$) + PG (6 mg kg^{-1}) and PG (6 mg kg^{-1}) + HCG (3000 IU kg^{-1}) also did not spawn. Degree-hours to maturation during the induced breeding trials varied widely from 487 to 724 with the type and dosages of hormone injected. The lowest degree-hours were observed in the trials with CPE injection followed by LHRHa and HCG.

Individual females released between 4.2 and 9.4 x 10^3 eggs when stripped, and the number of eggs generally increased with the female BW (P < 0.001; Figure 5, Table 2). Coelomic fluid content per female spawned ranged from 18.4 to 42.7 g and accounted for 18.3 to 31.0% of the total oocyte mass weight released (Table 2). Coelomic fluid content was highly correlated (P < 000.1) with the female BW (Figure 6).

DISCUSSION

Reproductive biology of *S. denticulatus*

Monitoring egg size in dissected ovaries over a period of three months (January, February, and March) clearly showed that eggs matured in stages. Three distinct size classes of eggs observed out of the spawning season suggests possible multiple spawning within a season. The gonadosomatic index monitored over a 12-month period showed that the ovary and testis become reproductively competent twice a year with two major peaks occurring in April and October. Additionally, the relatively high GSI observed from March to May and July to October indicated continuous maturation of eggs in the ovary throughout the warmer months. Overall, low maximum GSI (3.65%) also indicated that females might spawn over a several month period. Eggs developing in the ovary at various stages during the year suggest that this species, although typically thought to spawn twice a year, could be induced to spawn more frequently during warmer months.

Figure 5. Correlation between body weight of *Spinibarbus denticulatus* females and number of eggs released during hormone-induced strip-spawning (n = 190).

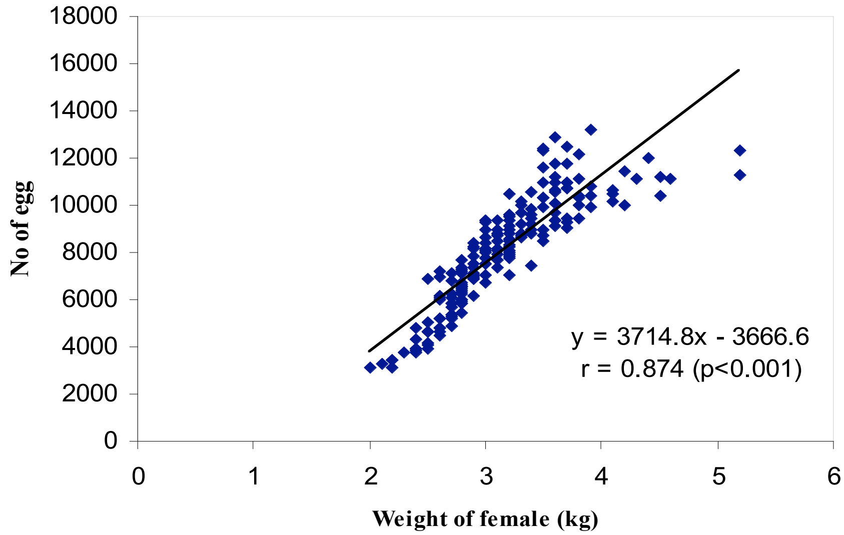
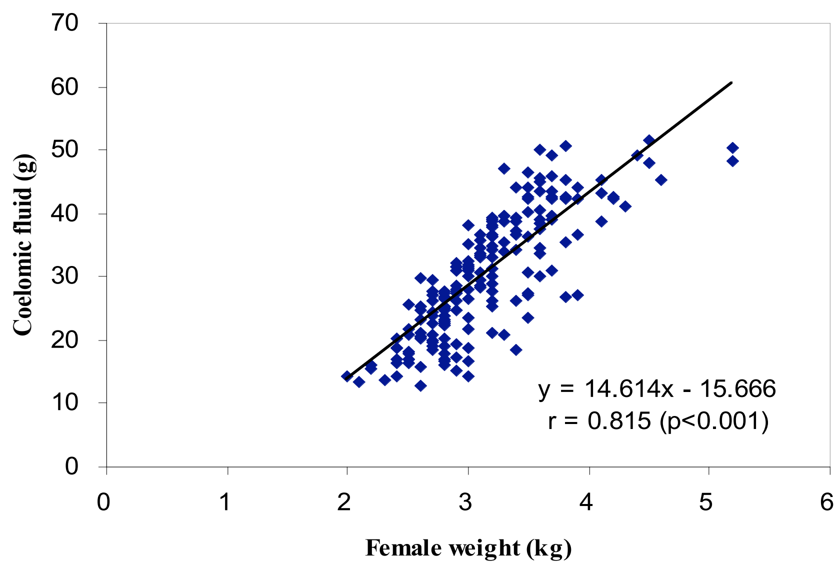


Figure 6. Correlation between body weight of *Spinibarbus denticulatus* females and coelomic fluid produced under induced breeding (n = 190).



Despite relatively low fecundity (9,873 ± 3,354 kg^{-1}) compared to grass carp, the yolk-filled egg size was larger (2.01 ± 0.03 mm diameter) than that typically found in other cyprinids indicating possibly more robust larvae with a potentially high survival rate; these are both important traits for an aquaculture species. The potential for multiple spawns per year and high fry survival rates could compensate lower fecundity rate per spawn.

Sperm characteristics of *S. denticulatus* were similar to other cyprinids with a short duration (1.99 ± 0.3 min) of progressive motility followed by vibration *in loco* (2.7 ± 0.3 min) before complete cessation of motility. The volume of expressible milt was low (3.3 ± 0.3 ml from 2.6 ± 0.5 kg^{-1} males). An attempt to increase total sperm by administration of LHRHa resulted in doubling the expressible milt to 6.2 ± 0.5 ml, but the total number of spermatozoa remained the same. Previous studies on induction of males have shown similar results (Kwantong and Bart, 2003). While the increased volume of milt would make artificial fertilization more convenient, whether there is any change in the quality of sperm from induced males needs to be determined.

The lack of recruitment in ponds where mature brood fish were held for two years suggested that perhaps pond-based husbandry is not conducive to natural spawning. Further studies on natural spawning, egg incubationk, and larval rearing conditions are required as well as induced spawning trials by manipulating the environment and/or endocrine hormones.

The annual rings of fin rays, otoliths, or scales are commonly used to assess the age of finfish (Geffen, 1992; Ikejima et al., 1998). Otolith reading requires sacrificing the animal, and pectoral fin assessment requires cross sectioning and the use of a stereomicroscope. However, the examination of scales in this study required only simple observation of the rings against a light source for them to be clearly visible to the naked eye. It is therefore the least invasive, and appears to be an excellent means to quickly assess age under field conditions.

Since the natural habitat of *S. denticulatus* has distinct cold and warm seasons and the rate of feeding and growth slowed in the ponds during the coldest periods, it was assumed that the dark rings indicated seasonal growth variation. This was verified by observing scales taken from the same male and female over a 12-month period. This preliminary study attempted to estimate the age of fish by collecting the broods from a known source and matching the age with presumed annuli rings. Moreover, observation of scales from the same male and female over a 12-month period suggested that annuli are in fact annual rings. Dark rings could also be caused by a number of other events including environmental stress or poor feeding during harvest and transport. Since study animals were collected from cages, further validation of this method of assessing age should be experimentally assessed.

These preliminary observations indicated that males were smaller than females as commonly observed in many other teleosts. This observation was based on both sexes having the same number of annual rings and farmers' accounting of the date and size at stocking. If such dimorphic characteristics do in fact occur, it would be important to understand when they become apparent in the life of this species.

Typically, the age of sexual maturation in tropical and subtropical species does not exceed two or three years. Observations of 37 females (2.9 ± 0.5 kg) sampled during the peak spawning period indicated that only five-year old females had sufficiently mature ovaries. The implication of this is that long-term investment would be required to develop and maintain broodstock, which could present an obstacle for low-input aquaculture. The determinants of precocious sexual maturation are thought to be environment, endocrine hormones, and domestication (Le Bail, 1988; Holland et al., 1996). Studies have also shown that long-term hormone therapy may also reduce the time to puberty in some species (Gur et al., 1995). This provides an opportunity to explore means to reduce the time to maturation by manipulating hormones, feed, nutrition, and husbandry practices.

Induced breeding

Attempts to breed *S. denticulatus* naturally by regulating environmental cues, such as water depth, water flow, and rainfall were largely unsuccessful, and the fish would not spawn naturally in captivity. Therefore, induced breeding of *S. denticulatus* is needed for successful culture of this species. This study for the first time demonstrated that intramuscular injection of LHRHa, CPE, and HCG are all effective methods for inducing final maturation and successful spawning of *S. denticulatus*. While all three hormones used could bring successful spawning, HCG was the least effective in inducing ovulation. Furthermore, the use of combined hormone strategy had no apparent advantage over single hormone strategy, and therefore the latter can be suggested to be the ideal for induced spawning of *S. denticulatus*.

Requirement of domperidone, dopaminergic antagist, to induce spawning in *S. denticulatus* was clearly observed in this study. Injection of LHRHa at doses of 30 and 40 μg kg^{-1} resulted in 25 and 50% ovulation, respectively; whereas LHRHa injected at similar dosages in combination with domperidone (10 mg kg^{-1}) resulted in 100% ovulation (Table 2). The lower rate of ovulation in females treated with LHRHa than fish injected simultaneously with LHRHa and domperidone clearly reflected the predominance of dopamine inhibition in the control of gonadotropin release in *S. denticulatus*. The role in potentiating the effects of LHRHa in several teleosts species by blocking the inhibitory effects of dopamine on gonadotropin release has been described by many others (Chang and Peter, 1983; Chang et al., 1984; Sokolowska et al., 1984; De Leeuw et al., 1985; Lin et al., 1985; Peter et al., 1988; Manickam and Joy, 1989; De Leeuw et al., 1989; Glubokov et al., 1991). Tan-Fermin (1997) reported that catfish *Clarias macrocephalus* failed to ovulate after treatment with LHRHa, but a high ovulation rate resulted when catfish were injected simultaneously with LHRHa and pimozide.

Ovulation response with HCG was lower than the stripping response obtained with LHRHa and CPE stimulation (Table 2). Though HCG has been used effectively in fish reproduction of some species, it is less effective if given alone (Epler et al., 1986). Using 30–40 mg CPE to replace 5000 IU HCG can produce a higher rate of spawning success in *S. denticulatus*. Previously, Lee et al. (1988) described CPE as a better spawning agent than HCG for induced spawning of grey mullet (*Mugil cephalus*). In this study LHRHa or CPE administration resulted in consistently high stripping response, fertilization rate, and hatch rate (Table 2), suggesting that LHRHa and CPE both are equally efficient for inducing spawning of *S. denticulatus*.

Given that this species does not spawn in ponds it will be necessary to develop a low cost method of induction. Although all the hormones tested are commercially available in Vietnam, LHRHa and domperidone may be too costly for a low input culture species such as *S. denticulatus*. Since HCG is relatively inexpensive compared with LHRHa and domperidone, some combinations of HCG and CPE need to be further tested in this species.

CONCLUSIONS

To culture a new species requires years of coordinated research, not only to understand its basic biology but also to manipulate this biology or environment to make the process feasible for culture. An early decision on the selection of an appropriate species for further targeted study minimizes failure and waste of resources. These preliminary observations on some of the important maturation and reproductive parameters of this promising species for more widespread culture provide essential information on the age of sexual maturation, gonadal development and reproductive cycle, male and female characteristics as well as fecundity and gamete characteristics. Furthermore, this study for the first time demonstrated successful hormone induced ovulation and artificial fertilization of *S. denticulatus*. The high (> 80%) fertilization and hatch rates obtained in this study showed the potential of the induced spawning protocol used in the study for its successful commercial application. This is the first study on the reproduction biology and seed production of *S. denticulatus*, which is expected to help in establishment of commercial hatcheries and thus, contribute to its aquaculture development.

ANTICIPATED BENEFITS

Now that we have successfully bred this species in captivity, when commercialized, it should lower seed collection pressure in natural population. Moreover, increased availability of seed in a more predictable manner at a lower cost increases the possibility of making this species more widely cultured throughout southeast. Availability of seed resulting in increased culture of this species would add one more low-cost freshwater fish to the list of aquaculture species with the potential to directly benefit the rural poor.

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BROODSTOCK DEVELOPMENT OF AMAZONIAN FISHES

Twelfth Work Plan, Indigenous Species Development 2 (12ISD2)
Abstract

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A preliminary study was carried out with 27 *Colossoma macropomum* broodstock between 4 and 11 kg donated by World Aquarium (Saint Louis, Missouri, USA) in two earthen ponds at Southern Illinois University at Carbondale (SIUC). Broodstock were pit-tagged and randomly distributed in three ponds. Water quality was modified to maintain three different environments (three different alkalinities, pH, conductivity, tannic acid content, transparencies, and TDS) emulating the three most common Amazon ecosystems where these fish naturally inhabit to evaluate water quality as a fish reproduction conditioning factor. Blood samples were collected prior to the start of feeding and will be collected once more after spawning. In one month, fish will be induced to spawn by hormonal injections and eggs from individual females incubated separately to monitor percentage of eyed embryos (13 hours after fertilization) and the hatching rate. Blood samples will be taken at the time of hormonal injection and at ovulation from at least four fish of each sex per dietary treatment. Blood plasma, seminal plasma (after centrifugation) and egg samples will be immediately frozen for later analysis at SIUC for hematocrit and steroid hormone analysis. Specific growth rates, food conversion ratios, and condition factors of broodstock will be compared between treatment groups. Survival of larvae at the free swimming stage will be considered as a final indicator of their quality. A duplicate study will be conducted next spring in Colombia, at Acuarios Leticia research station in Leticia, Colombia under the supervision of Universidad Nacional de Colombia and Instituto de Investigaciones de la Amazonía SINCHI.

INCORPORATION OF THE NATIVE CICHLID *PETENIA SPLENDIDA* INTO SUSTAINABLE AQUACULTURE: REPRODUCTION SYSTEMS, NUTRIENT REQUIREMENTS AND FEEDING STRATEGIES

Twelfth Work Plan, Indigenous Species Development 3 (12ISD3)
Abstract

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Some information has been obtained from wild populations of native species of fish, but little is known about their reproductive performance in captivity. In our laboratory we have studied some reproductive features of tenhuayaca (*Petenia splendida*), and we have found indications that tenhuayaca may be a very good candidate for aquaculture purposes. In Experiment 1, we determined the best sex proportion of adult tenhuayacas for reproduction in captivity. A recirculating system composed of nine 2,000 L plastic tanks was used. Brooders (20–30 cm, total length) were adapted to captivity conditions and placed in three treatments based on sex proportions (1:1, 2:1, and 3:1 F:M). In a triplicated block design, fish were randomly assigned to tanks. Six females were placed in each tank, while the number of males was adjusted according to the experimental design. Final numbers of fish per tank were: 12 for the density of 1:1; nine for the density of 2:1; and eight for the density of 3:1. Reproductive performance (spawning events, fry production, and survival) were evaluated for two months. Results indicated that the number of spawns were very similar for all treatments (28, 29, and 26, respectively). The largest number of fry were obtained in the 2:1 proportion followed by the proportions 3:1 and 1:1 (81,364; 65,778; and 55,035 fry, respectively). However, no significant differences were found between treatments ($P > 0.05$). Survival of fry was very high in all treatments (range 96.9–98.1%). Data from Experiment 2 is currently being analyzed. The experiment on the partial substitution of sardine meal for wheat gluten began on 27 August 2004. A total of 135 mature fish with an average size of 65 g and 19 cm TL were placed into 15-2 m diameter tanks using a completly randomized design (n=9). A sex ratio of 2:1 (females:males) was used. After one month of experimentation, no significant differences in weight or total length have been found between treatments. This experiment ends in November 2005. Other experiments will be conducted between November 2005 and April 2006. A final report will be submitted in June 2006.

BROODSTOCK DEVELOPMENT OF LARVAL FEEDING OF AMAZONIAN FISHES

Twelfth Work Plan, Indigenous Species Development 4 (12ISD4)
Abstract

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ABSTRACT

Induction of reproduction of the South American catfish (*Pseudoplatystoma surubim* sp.) broodstock raised in our facility at The Ohio State University was attempted on 2–15 March 2005. Fish were initially checked for signs of maturity (production of sperm by gentle pressure of the abdomen in males and oocyte biopsy using catheter in females). Sperm was collected from two males weighing 2,726 and 2,611 g. Sperm concentrations reached 6.88 10^9 spz ml^{-1}, whereas duration of motility in saline solution (0.35%) was very long (up to 13 minutes) in comparison to other freshwater fish species. On 14 March 2005, a female which presented oocytes with peripherical germinal vesicle was injected with two doses of carp pituitary extract (0.5 and 5 mg kg^{-1}) at 11-h intervals, whereas the two males that produced sperm and two other potential males were injected with a single dose of CPE (0.5 mg kg^{-1}). The female was observed regularly (2–3 hours) after treatment in accordance with the description given for *P. fasciatum* (Leonardo et al., 2004). Twenty-three hours after the second hormonal injection, a small quantity of eggs (18.7 g) was extracted upon abdominal pressure. Sperm was collected from the two previously identified males and concentrations reached 11.7 and 9.2 10^9 spz ml^{-1}, respectively. Sperm from each individual male (10 μl) was used to fertilize eggs (2 g) either in 10 ml water or saline 0.35% (triplicated treatments). The remaining eggs were inseminated with a mixture of sperm. Microscopic observations did not reveal any progress in embryonic development. Fertilization failed.

On 11 February 2005, we received surubim (*Pseudoplatystoma* sp.) larvae, two days after hatching, from the Aquaculture Center, Sao Paulo State University, Jaboticabal, Brazil (M.C. Portella). Larvae were offered live *Artemia nauplii* during the first week. Then we conducted a feeding experiment and reported for the first time the differences in diet acceptance, fish growth and diet utilization in surubim at early stages of ontogeny (10 mm, total length; experiment 1). In the second experiment with juveniles (25 mm), fish were offered *Artemia nauplii* and overperformed those transitioned to live tubificid worms or two commercial diets both in terms of weight gain as well as survival. Fish offered semi-purified diets based on casein/gelatin or synthetic dipeptides (50% protein), accepted formulated feeds, gained weight, and in the case of peptide-based diet had an excellent survival (85%). Juvenile surubim (initial weight 100.5 + 5.1 mg) grew best when offered the marine larval diet (Aglo Norse), however, severe cannibalism was observed. Results of substantial growth and no cannibalism in fish fed a peptide-based diet are particularly encouraging because this formulation may allow further evaluation of nutrient requirements in this species.

POND DESIGN AND WATERSHED ANALYSES TRAINING
Twelfth Work Plan, Water Quality and Availability 1 (12WQA1)
Abstract

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Variable rainfall distribution and terrain make surface water harvesting and storage a challenge in many developing countries. The overall goal of this study is to collect and develop information required to equip extension, nongovernmental organization (NGO) agents, contractors, and engineers for surface water development and aquaculture enterprise development in Latin America. A pond water balance for the levee production pond enabling determination of water flow required to balance seepage, evaporation, and direct rainfall was developed in English and Spanish on the Microsoft Excel® platform. The pump-in flow rate can also be determined for reaching a volume change per month target. A second model was formulated for evaluating surface water capture by watershed and/or hillside ponds for meeting the levee pond demand. Using hillside ponds that fill by impounding a fraction of total runoff (e.g., diverting water upstream) from streams appears to have promise for meeting water needs. A systematic approach using both models to reach a sustainable water supply target emerged from this work. Both the levee pond model and the water harvest model are based on balancing inputs and outputs given monthly rainfall patterns. A simple approach to mechanical spillways preliminary design was developed. The models are adaptable to any location if key input data is available, particularly average monthly rainfall and storm frequency-duration data. The models do not address water quality issues. The software is intended for watershed sizes not larger than 500 ha and storage ponds of less than 5 ha surface area x 4 m depth due to relationship limitations and safety concerns. Coupling with other cooperative development concerns, such as marketing associations, provides a platform for helping groups of people in a watershed to realize further the potential of enlightened self-interest in developing common solutions to water problems.

ELIMINATION OF METHYLTESTOSTERONE FROM INTENSIVE MASCULINIZATION SYSTEMS: USE OF ULTRAVIOLET IRRADIATION OF WATER

Twelfth Work Plan, Water Quality and Availability 3 (12WQA3)
Abstract

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Masculinization of tilapia fry by oral administration of 17α-methyltestosterone (MT) is considered the most successful method employed; however, under certain conditions this technique is sometimes less favorable. Furthermore, significant “leakage” of MT into the pond environment may occur from uneaten or unmetabolized food. This leakage poses a risk of unintended exposure of hatchery workers, as well as fish or other non-target aquatic organisms, to the steroid or its metabolites. We propose the use of intensive systems for masculinizing tilapia fry using MT-impregnated food at a large scale where excess MT is eliminated from the water by means of continuous filtration through UV sterilizers. This study is testing the hypothesis that MT could be eliminated from the water used in intensive sex-inversion systems using UV sterilizers. We are currently running tests in our systems, and experimental runs will be conducted from October 2005 to February 2006. Water samples (20 ml) will be extracted with Sep-Pak cartridges and sent to Oregon State University to determine levels of MT. A final report will be submitted by June 2006.

ELIMINATION OF METHYLTESTOSTERONE FROM INTENSIVE MASCULINIZATION SYSTEMS: USE OF SOLAR IRRADIATION AND BACTERIAL DEGRADATION

Twelfth Work Plan, Water Quality and Availability 3 (12WQA3)
Abstract

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It is well known that one of the major problems in aquaculture is the elimination of culture wastes from water. The amount and type of residues will depend on the species cultured, the stage of development, and the feeds used. To lower the environmental impacts caused by aquaculture practices, different technologies have been developed to preserve water quality and reduce residue levels during fish culture. These systems are known as recirculation aquaculture systems (RAS) and are widely used because they allow for efficient disposal of wastes in aquaculture. In a previous investigation we developed a RAS to eliminate methyltestosterone (MT) from aquaculture effluents in an intensive system for masculinizing tilapia fry at a large scale. In this system, the excess MT was eliminated from the water and the substrate by means of continuous filtration through activated charcoal filters. Our RAS is composed of a submersible pump, sediment trap, charcoal filter section, mechanical filter section, biological filter section, and a water curtain with sunlight exposure. In this experiment, we were able to demonstrate that MT is eliminated from the water; however, we wanted to determine if bacteria in the biofilter and sunlight played a significant role in eliminating the steroid. The goal of this investigation is to determine if the bacteria present within our RAS are capable of degrading MT. The ultimate goal of our research will be to isolate, characterize, and cultivate the species of bacteria responsible for degradation of steroids. We are currently building the filters needed in our tanks, and experimental runs will be conducted from October 2005 to February 2006. Water samples (20 ml) will be extracted with Sep-Pak cartridges and sent to Oregon State University to determine levels of MT. A final report will be submitted by June 2006.

ECOLOGICAL ASSESSMENT OF SELECTED SUB-WATERSHEDS OF THE NZOIA RIVER BASIN

Twelfth Work Plan, Water Quality and Availability 4 (12WQA4)
Abstract

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Perhaps the single most important variable in achieving sustainable watershed management is understanding and underpinning key land use practices that directly or indirectly affect ecological processes and system functioning. The reliance on land for agrarian production in rural Kenya, coupled with dependence on land resources for economic livelihood, places an enormous premium on resources derived from land, and as a consequence leads to degradation and hence loss of ecological integrity of the system. A sustainable land management strategy requires not only intervention at site-specific locations but also the landscape level. A system approach is needed to disentangle critical landscape components, and linkages and will more likely to lead to overall positive impacts on the watershed. The Nzoia watershed system transcends a broad range of land use systems and practices, ranging from small-scale holder farmland to large scale mechanized agriculture, and cuts a cross a tenure regime of private ownership to public land (e.g., forest reserves and national parks). The watershed occurs in generally high potential and high population region of the country, and therefore the influence of land use on the system is extremely important.

Aside from the analysis of land use practices and associated possible environmental effects, another key aspect of this component is to examine the role and influences of prevailing policies and laws as drivers of land use practice, i.e., the extent to which the land use systems and practices are guided or influenced by existing laws and policies. Also important is an understanding of how much overlap or synergy exists between various land-related policies and legislation and how these might impede sustainable land use management at the site-specific level and overall watershed system. Critical questions that need to be addressed in this component include: How much environmental /land use policy and legislative awareness exists amongst the rural population within the watershed? What policy or legal provisions exist for mitigating against negative environmental impacts of land use practices, e.g., use of pesticides and herbicides?

A Michigan State University graduate student, Heather Platt, studying with Geoff Habron of MSU, is well settled for a two-month stay in Eldoret, Kenya. Two areas within the Kapolet and Moiben subwatersheds have been targeted for Participatory Rural Assessment (PRA) analysis. Three assistants, a driver, and a vehicle to assist with data collection have been engaged.

DETERMINATION OF HYDROLOGIC BASELINES FOR THE NZOIA RIVER BASIN

Twelfth Work Plan, Water Quality and Availability 5 (12WQA5)
Abstract

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The degradation of the Lake Victoria basin has received international attention. The 184,400 km^2 basin drains 14 major rivers with an estimated population of 25 million people. The Kenyan portion of the basin drains 42,000 km^2 with a population of 7.9 million people. The Nzoia watershed comprises 12,000 km^2 of the Lake Victoria basin. Four main processes drive the degradation of the Lake Victoria basin: 1) loss of 89% of forest cover to poor agricultural practices causing erosion and sedimentation; 2) pollution from mines, urban areas, and industry, leading to sedimentation in eutrophication; 3) loss of lake fish species diversity due to introduction of the non-native Nile perch; and 4) poor fisheries management practices. Sedimentation increased fourfold in the last 100 years, with some areas demonstrating losses of 200 horizontal feet each year.

Kenya is on the verge of substantial agricultural development and urbanization, especially in the Nzoia basin. A search of the literature reveals that virtually every agricultural enterprise, from forestry production to container nursery production, has specific Best Management Practices (BMPs) for water quality management with nonpoint source inputs. The US-NRCS has an exhaustive array of BMPs available for agricultural production nonpoint sources. BMPs have recently been published for urban storm water management. Except for specific cases not involving soil tillage (e.g., container nursery in greenhouses), sediment is the most significant pollutant. Sediments are significant in both urban and rural development because a host of chemical constituents adhere to sediment particles. BMPs for urban and rural environments focus primarily on sediment removal and handling. Increased urbanization and increased intensity of agricultural production results in an increased magnitude and frequency of runoff events, reduction of base flow, and increased stream velocities when flowing. These flow changes lead to increased cross-sectional areas, significant down-cutting (unless stream is already heavily armored), increased sediment loads due to bank erosion, urban construction or intensifying agricultural production, modification of streambed to include more fine particles, and subsequent stream modifications being required to reduce flooding risks. Increased urbanization and agricultural development affect water quality as well. Urbanization causes an initial pulse of sediment that subsides as the development stabilizes. Increased agricultural production increases pesticide and sediment loads, which may remain high depending on the degree of soil tillage. The sediment load and consequent increase in fines cause benthic ecology to become much less diverse. Streams generally shift from an external (leaf matter) to an internal (algal organic matter) food chain. The stream community loses diversity and wetlands, springs, and riparian buffers are damaged or lost due to excessive sediment, toxic compounds, or both. The effects on receiving bodies (e.g., Lake Victoria) are felt over longer time frames. After visible refuse and damage to aesthetics, nutrient enrichment and the resulting increase in primary productivity is the most visible sign of development. Lakes act as sinks for sediment-laden materials and take longer to recover from contamination than do streams. Heavy metal absorption, sediment deposition patterns near the outlet, increased algae production in the lake (which indicates possible eutrophication that can in turn lead to fish kills), loss of

desirable species, and increased "trash" fish species are documented to occur with development. These documented trends will be pivotal in prioritizing the work on the Nzoia basin. It is not too late to avoid these effects.

The Nzoia basin is in the initial phases of development. Much cultivation in rural areas is conducted by women of the families on soils at the river edge. Environmental legislation on the books provides 30 m buffers; however, the exact point of measurement of the buffers is legally unclear and thus there is no effective enforced buffer. A buffer design is needed that will preserve some of the existing benefits of being near the river while achieving water quality goals. Environmental quality within and around the Lake Victoria basin, is closely linked to land use practices (GEF, 2004). Some of the land uses have resulted in serious degradation of ecological integrity and hydrologic processes within the watersheds. This is shown by the loss of biodiversity and habitats as well as altered hydrologic regimes. Consequently, the trend has resulted in declining livelihoods of the inhabitants. These factors have contributed to overall poverty in the region. With this background, there is a need to develop strategies and mechanisms to stabilize and rehabilitate the watersheds in the region. The proposed project will embark on a multidisciplinary approach to develop and demonstrate improved and integrated sustainable management of watershed resources at a watershed scale. The watershed assessment effort and subsequent demonstration projects will be coordinated with the needs of the Kenyan Department of Fisheries in terms of fostering aquacultural enterprises along the river and preserving the Lake Victoria fishery. Overall, the proposed project will complement other efforts to the region in create sustainable, interdisciplinary broad-based watershed rehabilitation models through technical, social, and policy interventions in land use and natural resources management. The fisheries department can provide much helpful reference information to provide an objective standard by which improvements can be measured.

The Nzoia basin contains a variety of geomorphic formations, ranging from pristine fast moving stream, wetlands, lakes, and discharge into Lake Victoria. Selected stations will be characterized for selected indicator species of river health. At least one existing industry (sugar processor or paper mill), an upland wetland, and lakes will be assessed for species composition and diversity.

A watershed water resources assessment is the basis of determining the possibilities of water resource utilization, control, and development. A proper assessment requires the determination of the sources, quantity, and quality of water resources which, in this study, the initial baseline data to assess the conditions in the watershed will be collected. First, an inventory and mapping of the characteristics of the watershed will be undertaken. Next data collection stations will be established at key locations for water quantity and quality measurements.

The US NRCS developed the Universal Soil Loss Equation. The USLE predicts soil detachment. Soil delivered to some point below the erosion location may be predicted using a sediment delivery ratio. The US Forest Service published an approach for evaluating sediment delivery ratios through buffer strips. Coupling the NRCS soil loss equation with the Forest Service delivery ratio estimation approach enables the computer modeling of buffer strip scenarios that can prove efficacious for water quality preservation.

A graduate student studying with Bill Tollner, Herbert Ssegane of Uganda, has arrived at Georgia to begin an M.S. degree. He is reviewing the literature with a goal of developing an erosion simulator useful as a demonstration tool for showing the benefits of proper stewardship of stream banks and riparian areas. This tool is envisioned to have benefits relevant to problems in Ethiopia, Kenya, and Uganda.

COST EVALUATION AND BENEFIT ASSESSMENT OF FISH FARMING IN SELECTED AFRICAN NATIONS

Eleventh Work Plan, Economic/Risk Assessment and Social Analysis 2 (11ERA2)
Final Report

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ABSTRACT

Record keeping is an important management tool necessary for business planning and development. If small- and medium-scale fish farming enterprises can be sustained, developed and be profitable, steps should be taken to teach farmers basic valuation methods for costs and benefits at the farm level as well as principles of record keeping. This project involved training sessions for selected fish farmers in Kenya and Ghana. In Kenya, the five-day session trained fish farmers in pond record keeping and business management. Twelve small-scale fish farmers and hatchery owners participated in the training. The session focused on cost and benefits of constructing good ponds, how to increase fish production through better pond management, pond financial management, and pond record keeping. Results from this workshop showed that farmers found that analyzing production records was necessary to identify weaknesses in farm operation. Farmers also recognized that record keeping was valuable for gaining potential bank loans. In Ghana, the training involved 85 farmers. The focus of the training was record keeping and economic analysis, i.e., how to calculate costs and profits. The training session was conducted in collaboration with the Ashanti region and Brong-Ahafo region farmers associations. Results from this workshop showed that farmers appreciated the importance of record keeping and were able to value home-made inputs, identify and list all various farm records, and also identify constituents of fixed costs, recurrent costs, revenues, and profits.

INTRODUCTION

It has been reported that farmers who have participated in ACRSP aquaculture development research activities continue to improve in production of farmed fish and have become model farmers (Veverica et. al, 2002; Mac'Were, 2002). Producing more fish does not necessarily imply profitability of the fish farming business. Record keeping is an important management tool necessary for business planning and development. If small- and medium-scale fish farming enterprises can be sustained, developed and be profitable, steps should be taken to teach farmers basic valuation methods for costs and benefits at the farm level as well as principles of record keeping.

Small- and medium-scale fish farmers do not receive financial assistance from commercial lending institutions or the government because of the absence of the necessary economic data and information on fish farming. A visit to commercial banks and the Agricultural Finance Corporation (a government lending agency) in Kenya recently revealed that no financial assistance has ever been given towards fish farming. In most African countries, the government provides all sorts of support for farming of traditional agricultural commodities. Farm-level information on production, costs, sales, inventory, etc., could assist fish farmers in evaluating the profitability of their fish-farming ventures. The information is needed for the preparation of enterprise budgets and business plans to secure the needed financial assistance and support for investments and development. Consequently, this activity trained farmers on simple methods for assessing and evaluating costs and benefits as well as principles of record keeping. Training was needed to highlight the importance of data for the preparation of business plans that are essential for securing financial assistance from commercial lending institutions. Consequently, the objectives of this activity were:

1. To teach farmers simple methods for assessing and evaluating costs and benefits.
2. To teach farmers principles of record keeping.

MATERIALS AND METHODS

In Kenya, a training workshop for 12 small-scale fish farmers and hatchery owners was held from 18 through 22 July 2005 at Moi University, Chepkoilel Campus, Eldoret. The session focused on cost and benefits of constructing quality ponds, how to increase fish production through better pond management, pond financial management, and pond record keeping. Teaching modules developed by resource persons from University of Arkansas at Pine Bluff and Moi University were used for the training. Farmers were selected on the basis of their level of production. However, farmers that participated in the on-farm trials held in 2000 under work plan nine were selected for continuity. Among them were three farmers that have constructed and are operating catfish fingerling hatcheries. Fish farmers were encouraged to bring information on inputs used for fish farming including household food materials, and also bring various kinds of farm records kept at the farm. A majority of the farmers had some understanding of records such as yield, production, costs, sales, liabilities, inventory, and profit and loss. It was noted that many small-scale fish farmers financed their farming enterprises with revenues from other agriculture enterprises. The trainees included both male and female farmers. The training utilized techniques such as illustrations, discussions, and group projects and presentations. Teaching resources that were used included PowerPoint presentation of developed modules, flipcharts (on few occasions), and handouts. The medium of instruction was English because all farmers understood and were able to communicate fairly well in English.

Participants were given teaching modules on pond construction, pond management, and hatchery management as well as economic analysis, financial record keeping, production record keeping, and marketing through record keeping. Most seminar presentations were in PowerPoint. Handouts of the notes were given to the participants and allowed them to concentrate on the topics of discussion. Farmers also worked in discussion groups where record keeping needs were explored. Each farmer contributed to these brainstorming sessions with all ideas written on a flipchart. Farmers were taken to the Moi Fisheries Research Station and the hatchery on campus for updates on new technology, primarily in the area of Clarias propagation. A day-long field trip to three of the participants' farms allowed the farmers to see how other people run their production operations as well as view their record keeping process. Time available was a constant problem and we usually exceeded the daily schedule by two hours.

An evaluation questionnaire was administered to the participants at the end of the program. Interestingly, record keeping was rated the most interesting topic presented, but when asked where changes would be made in their operations, most spoke about changes in hatchery and pond management. Only one respondent indicated financial records would be modified. Most farmers indicated they either had not yet had sales or they were not turning a profit. When asked about new management techniques learned, most indicated areas in pond management or hatchery management. About a third indicated they learned new record keeping techniques.

In Ghana, the training involved 85 farmers. The focus of the training was record keeping and economic analysis, i.e., how to calculate costs and profits. The training was held in Kumasi at the offices of the Ministry of Food and Agriculture from 27 through 30 June 2005. The training session was conducted in collaboration with the Ashanti region and Brong-Ahafo region farmers associations. Teaching modules developed by resource persons from University of Arkansas at Pine Bluff and Kwame Nkrumah University of Science and Technology, Kumasi were used. Participants at the training session came from the 10 administrative districts in the Ashanti and Brong Ahafo regions of the country. These districts constitute the main areas of considerable fish farming activity in the country, and also reflect the various levels of fish farming in Ghana. Many participants lacked basic economics knowledge in several aspects of fish farming, although they have been farming fish for considerable periods. The training took the form of brief lectures, explanations and interactive processes.

RESULTS AND DISCUSSION

In Kenya, the training was generally successful. The farmers now have skills in assessing costs and benefits as well as basic record keeping skills. Results from the workshop indicated that farmers found analyzing production records will point to weaknesses in their operation. Participants also recognized that they are deficient in certain skills (e.g., economic analysis), but with good record keeping and assistance from professionals they will be able to adequately handle and interpret farm records. In general, participants recognized the value of record keeping and its importance in gaining potential bank loans. More importantly, farmers realized they have two individuals (John Mackambo and Sara Njugunda) at Moi University willing to assist them in these areas. Farmers even discussed the possibility of paying for the service. Willingness to pay for such a benefit is extremely important and indicates advancement in rural development.

In our verbal discussions before and after the evaluation was filled out, the concept that record keeping might open doors at banks or the Agricultural Finance Corporation (AFC) for business loans was considered by the farmers. Indeed, it was announced one of the farmers had just received word he is approved for an AFC loan. He also mentioned that two other farmers from his region had their loans approved. This is the first such loan to a fish farmer. This announcement seemed to stress record keeping necessity to the group. Incidentally, in a previous workshop, the farmer who received the loan had been awarded best record keeping skills by the resource personnel. This reinforces the link between record keeping and loan eligibility. This same farmer arrived at the workshop with his farm records in hand and after the production record keeping session, he indicated he had never before recognized how his records could identify production weaknesses. Although he had written down results from year one and year two, he had never thought to ask the question of why was production greater but less profitable in year two compared to year one. If the workshop stimulated more such realizations, the benefits should be evident in the future.

In Ghana, besides the teaching of record keeping and economic analyses, there were sessions on pond construction, pond management, and fish feeding. An initial assessment of participants revealed that farmers had little or no idea on pond construction and management. They also had very minimal knowledge on stocking densities or handling fingerlings, especially how to reduce fingerling mortality and enhance survival. Knowledge of these techniques was fragmentary. Regarding fish feeding, there was no feeding frequency, feed rationing or feed formulation.

Participants had little knowledge about monitoring and maintaining suitable water quality such as pH and dissolved oxygen levels. None of the farmers monitored water quality parameters of their fishponds. None of the farmers kept any fish farm records, and those who kept any form of records did so in an unreliable manner. The training session therefore touched on a bit of each of those issues but with the main focus on record keeping.

Overall, the training session was successful but could have been better planned. Since it was the first training experience for farmers, there were some logistical problems, especially dealing with the association. Nevertheless, interaction with participants after the training indicated that farmers appreciated the importance of record keeping and were able to value home-made inputs, identify and list all various farm records, and identify constituents of fixed costs, recurrent costs, revenues and profits.

In Tanzania, the training could not be conducted because of the need to expand the materials to teach farmers. Consequently, a five-day training workshop has been planned for the spring of 2006 that will be conducted in collaboration with Moi University, Kenya. The major topics to be covered are pond construction, pond management, fish health, fish nutrition, economics of production, and marketing. Training instructors will come from Sokoine University of Agriculture, Kingorwila National Fish Center, Moi University in Kenya and University of Arkansas at Pine Bluff, US. The training activities will be based on training modules and trainees will include women and household members who manage fishponds.

ANTICIPATED BENEFITS

From this training, fish farmers would begin assembling data and information that would be useful for securing loans from financial institutions, including government lending agencies. Financial institutions will be better informed about the economic viability and the relative profitability of the fish farming business compared to other traditional agricultural enterprises. The fish farming business will then be in a position to obtain the needed financial assistance for investment in the industry.

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AN ECONOMIC ASSESSMENT OF AQUACULTURE IN RURAL AFRICA: THE CASE OF TANZANIA, KENYA AND GHANA

Eleventh Work Plan, Economi/Risk Assessment and Social Analysis 3 (11ERA3)
Final Report

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ABSTRACT

An economic assessment of aquaculture in rural Tanzania, Kenya, and Ghana was conducted using representative Nile tilapia production systems in each nation. We used a dynamic economic model to analyze the profitability of three Nile tilapia production cultures that included a mixed-sex tilapia culture without catfish predation, mixed-sex tilapia culture with catfish predation, and hand-sexed all male tilapia culture. The model simulated individual fish growth, taking into account fish population dynamics in the pond. In Kenya, the results suggest that mixed-sex tilapia culture, though economically feasible and profitable, was inferior to all male tilapia cultures. Switching from no catfish predation to predation culture did not significantly increase operational costs. The realized gross profit margins were 45% for a 200 m^2 pond and about 19% for a 634 m^2 pond. With the exception of mixed tilapia without predation in the 634 m^2 pond, the realized gross profit margins were generally over 40%. Introduction of catfish predation in the pond decreased profit margin from 46% to 43% for a 200 m^2 pond but increased profit margin from 19% to 42% for a 634 m^2 pond. Culturing hand-sexed all male tilapia increased gross profit by 46% and 56% for 200 m^2 pond and 634 m^2 pond, respectively. In Ghana, the mixed-sex tilapia culture with catfish predation and hand-sexed all male tilapia culture were economically attractive. Switching from polyculture to monoculture did not significantly increase operational costs. The realized gross profit margins were about 26% for polyculture and 35% for monoculture. By culturing hand-sexed all male tilapia, gross profit margins increased from 26% to 39% for a 2,000 m^2 pond and from 26% to 46% for a 4,000 m^2 pond. In Tanzania however, though economically feasible, the mixed-sex tilapia culture did not generate enough profits for long-term business survival. Switching from no predation to predation culture did not significantly increase operational costs. The realized gross profit margins were 2% for a 150 m^2 pond and 4% for a 300 m^2 pond, which were not high enough to justify a mixed-sex tilapia culture without predation. Introduction of catfish predation in the

pond increased the profit margin to 27% for a 150 m^2 pond and to 23% for a 300 m^2 pond. The culture of hand-sexed all male tilapia increased gross profit margin to 47% and 30% for 150 m^2 pond and 300 m^2, respectively. These results suggest that technical assistance to rural aquaculture in Africa would be best with research and extension geared towards developing Nile tilapia production systems based on all male tilapia and not polyculture. Since a mixed-sex culture with catfish predation was economically feasible in all countries, it should represent a second best alternative for Nile tilapia production system. Farm sizes differed among the three countries and research efforts would be needed to determine optimal farm size for each country. Optimal farm size ensures efficient use of resources. Under improved production system, the models showed profits were high enough to justify investment through borrowed capital.

INTRODUCTION

In most African countries, smallholder fish farmers do not receive financial assistance from commercial lending institutions because of the absence of the necessary economic data and information on fish farming. Farm-level information on production, costs, sales, and inventory could assist fish farmers in evaluating the profitability of their fish-farming ventures. The information is needed for the preparation of enterprise budgets and business plans to secure the needed financial assistance and support for investments and development. Some studies have demonstrated that fish farming is a viable enterprise for Africa with high gains, but minimum costs (Molnar et al., 1991; Lightfoot et al., 1996). Engle et al. (1993) showed that fish production in Rwanda was a main cash crop for over 50% of farmers. Wijkstrom and MacPherson (1990) indicated that while large-scale and intensive aquaculture enterprises have proven to be beyond the means of most farmers in Africa, small-scale aquaculture with commercial orientation could be a profitable economic activity.

In Tanzania, more than 95% of the farmers culture Nile tilapia (*Oreochromis niloticus*) in earthen ponds under mixed-sex culture. Farmers use naturally available feeds. Ponds are commonly fertilized with domesticated animal dropping or tender leaves as compost manure. Feeds vary from area to area depending on availability. The most commonly used feeds are rice and maize bran, kitchen leftovers, and garden remains. Tanzania fisheries policy emphasizes semi-intensive integrated fish culture, focusing on Nile tilapia species. Nile tilapia species are given priority due to their positive characteristics that include fast growth, short food chain, efficient conversion of food, high fecundity, which enable distribution of the fingerlings from farmer to farmer being possible, tolerance of a wide range of environmental parameters, and good table quality. The disadvantage with Nile tilapia culture is early sexual maturity that leads to overcrowding in the pond and thus stunted growth.

The development policy of the Kenya government focuses on alleviating poverty through increased food production and minimizing environmental degradation. Consequently, aquaculture is a major priority development initiative of the government to increase available protein to local communities (Ngugi and Mayala, 2000). However, aquaculture contributes less that 1% to the total national fish production. Water limitation and unknown returns from aquaculture investment have contributed to slow growth of the aquaculture sector in Kenya. Because of limited knowledge, fish farming is seen as a marginal and risky investment. However, commercial fish farming has experienced some degree of success particularly in trout hatcheries for restocking inland water for angling and supply of fingerlings to fish farmers. Stocking of ponds has been done with supplies from other farms, from government fish farms or demonstration ponds, and from the wild (lakes and reservoirs).

Tilapia monoculture in Kenya represents over 75% of aquaculture with polyculture of tilapia and catfish constituting 15%, trout 5%, and the remaining 5% consists of catfish culture and other species (Ngugi and Mayala, 2000). Currently, the Department of Fisheries together with other development agencies are involved in promoting commercial hatcheries for seed production, ensuring the transfer of small-scale and commercial aquaculture technology, providing training in aquaculture, establishing more hatcheries, and training fish farmers and fisheries extension officers. Research and extension linkage mechanisms are established mainly through training of extension personnel at research institutes and interaction between senior officials of the Fisheries Departments and University researchers.

For centuries, Ghana has depended on capture fisheries from both marine and inland waters. The dwindling marine fisheries resources and over-fishing in inland waters have forced Ghanaians to explore the opportunities offered by aquaculture. Countrywide, there is a fish production deficit of 400 metric tons. The Ghana government spends an average of US$200 million to import fish to supplement local production. There is a ready market for fish because fish constitutes about 60% of the protein intake in the country. For decades, the fisheries department in Ghana has been under the Ministry of Agriculture and this constituted a formidable setback in aquaculture development in the country. During the early part of 2005, a separate Ministry of Fisheries in Ghana was created. A Pilot Aquaculture Centre (PAC) was also established.

The first National Aquaculture Policy of Ghana was initiated in 1998 and the final review has only recently been completed. It stipulates that the aim of the national aquaculture policy (NAP) is to develop a sustainable aquaculture production system to increase fish production for local consumption and export markets. The aquaculture sector is expected to contribute toward economic growth, food security, and poverty alleviation of present and future generations of Ghanaians. The overall goal or developmental objective of NAP is to establish the national sector framework outlining the responsibilities, duties, and obligations of regional cooperation, government, local authorities and persons involved in aquaculture. This is to facilitate, promote, regulate, and to protect the sustainable development and management of aquaculture and culture-based fisheries in national and shared water bodies and ensuring equitable and sustainable socioeconomic development.

This study assessed the economic viability of aquaculture in rural Tanzania, Kenya, and Ghana using representative Nile tilapia production cultures in each nation. The study focuses on economic profitability of small-scale production with the following objectives:

1. To evaluate smallholder, medium-scale, and community-based aquaculture ventures within rural areas.
2. Identify researchable themes and areas of intervention.

MATERIALS AND METHODS

The study involved a survey of households involved in aquaculture in Ghana, Kenya, and Tanzania. The survey was conducted between January and April 2005. The sample of farmers surveyed included 124 in Ghana, 138 in Kenya, and 148 in Tanzania. Data from the survey indicated that pond sizes varied considerably among the three nations and polyculture of Nile Tilapia and catfish was the main culture techniques in all three countries. For example, in Ghana, pond sizes varied from 300 m^2 to 18,000 m^2, with the majority having between a 2,000 m^2 to 4,000 m^2 pond. Nile tilapia accounted for 90% of the primary farmed fish by the sample households. The secondary farmed fish was catfish, which was used to control overcrowding in the pond. In Kenya, pond sizes varied from 40 m^2 to 7,200 m^2, with majority of the sample having 200 m^2 ponds. The average pond size was 634 m^2. In Tanzania, whereas the pond sizes varied from 6 m^2 to 18,900 m^2, majority of sample households had either a 15 m × 10 m (150 m^2) or a 15 m × 20 m (300 m^2) pond.

The analyses were conducted to determine the profitability of mixed-sex tilapia culture with or without catfish predation and hand-sexed all male tilapia culture for various representative pond sizes in the three countries. Sex-reversal is currently considered high-tech and unsustainable in the current aquaculture production system in many sub-Saharan African countries. From the survey data, the representative aquaculture farms used for the analysis were 200 m^2 and 634 m^2 pond sizes in Kenya, 2,000 m^2 and 4,000 m^2 pond sizes in Ghana, and 150 m^2 and 300 m^2 pond sizes in Tanzania. Other data used for the analysis included type of Tilapia culture, stocking densities, type of feed used, number of days taken to grow the fish and economic information on price of fish, and operation costs and investment. The model results give indication on investment, labor costs, feed and other input costs, expected price for different categories of fish at harvest, and financing performance of different farm management options. The generated results are robust enough to develop standard farm enterprise budgets and business plans.

A simulation model of de Graaf et al. (2005) for the production of Nile tilapia in a mixed-sex or mono-sex cultures and with or without African catfish (*Clarias garieoinus*) predation was developed. The model allows simulating the production potential of the selected pond size. There are two kinds of simulation models for fish reared in ponds: descriptive-empirical models and explanatory-theoretical models. Explanatory-theoretical models are based on the knowledge of biological process and flow underlying the production system. While biogenetic models balance the flow of energy, mass, nitrogen, and respiration (Ross and MacKinney, 1989), population dynamic models balance numbers of fish or biomass in the production system (Fischer and Grant, 1994).

de Graaf et al. (2005) presents the economic simulation model based on population dynamics implemented through Tilapia Farming Support Tool (TFST) software (Nefisco, 2003). The advantages of population dynamic models include allowing incorporation of prey-predator relationship in the model, and modeling based on individual fish growth dynamics (Sparre and Venema, 1992). The de Graaf et al. (2005) model consists of two modules. The first module simulates the growth of tilapia males, females, and recruits. The second module simulates stocked predators. Each module is based on the principle of length-based fish stock assessment, whereby growth is simulated according to the von Bertalanffy growth function (Somers, 1988). The change in the number of fish is simulated with an exponential decay function as discussed in Sparre and Venema (1992). Details of the model structure are presented in de Graaf et al. (2005) and the TFST software that can be downloaded from the Nefisco Foundation website.

The model was calibrated based on the results of 62 rearing experiments carried out in Congo Brazzaville during 1986 and 1990. The input data set were pond size, number of rearing days, length of the stocked fingerlings, proportion of male fingerlings at stocking, numbers and lengths of predators, and feeding levels. The model was validated with three different data sets. The first data set was from 24 experiments carried out by the Center for Tropical Forestry in the Ivory Cost in 1979 and 1980. The second data set was used to validate the outcome of a high density of large catfish (*Hemichromis fasciatus*) on recruitment. The second data set was from 104 experiments with poly-culture of Nile tilapia with snakehead murrel (*Channa striata*) carried out in 1978 and 1979 by the Central Luzona State University in the Philippines. The data were used to estimate overall growth rate of tilapia and simulate the impact of predation by snakehead murrel. The third data set was from 18 experiments with poly-culture of Nile tilapia with snakehead murrel carried out in 2000 by the Asian Institute of Technology in Thailand.

Calibration and validation was carried out by adjusting the value of key parameters on mortality and growth reduction because of the biomass of fingerling. The simulation was conducted until the best agreement between observed and simulated data was reached. The agreement between simulated and observed values was quantified through linear equations and the Pearson's correlation coefficient was used to examine the significance of the relation. Sensitivity analysis was done to investigate the impact of four model input parameters (i.e., growth parameter, stocking length of Nile tilapia fingerlings, length at first maturity of Nile tilapia and the recruitment on stochastic behavior of model outputs). Tables 1 and 2 present the model components equations, used to balance the dynamics in the model and the parameters of the model.

The main structure of the model consists three parts. The first part is the database that contains information provided from the survey data. The second part is the program that simulates the growth of fish in the pond using equations and parameters in Tables 1 and 2. The simulation exercise generates information on expected yields and size and weight of fish at harvest. The optimization part combined all information to generate economic variables that are used to select

Table 1: Components of the model and parameter values.

Description	**Variables**
Number of fish in ponds: $N_t = N_0 e^{(M_t + P_t)t}$	N_t : Number of fish at time t. N_0 : Initial number of fish at t=0. M_t : Natural mortality rate. P_t : Predator related mortality rate.
Length increment by individual fish [a]: $\partial L/\partial t = K(L_\infty - L_t)$.	K : von Bertalanffy growth constant L_∞ : von Bertalanffy maximum length cm). L_t : Length of fish (cm) at time t.
Normal distribution around the mean: $V = V_0(1+z) \quad z \sim N(0,CV)$, (i.e., $K \pm V$ and $L_\infty \pm V$).	V : Randomly generated number. V_0 : mean of V. z: A random number generator with a mean zero and variance of CV.
Variation based on feed crude protein: $CV = \beta_0 + \beta_1(\%CP)$.	CV: Coefficient of variation. β_1=19.015 and β_2=0.523
Growth of parental stock and reduction in growth rate: $K_t = K_0 e^{-\beta_2 P_\alpha}$. $K_{t+1} = K_t e^{-\beta_2 P_\alpha}$.	K_0 : Initial value of K. P_α : Proportion of fingerlings in the pond on a weight basis and β_2=0.04.
Probability of dying: $P_{d,t} = 1 - e^{(M_t + P_t)t}$	$P_{d,t}$: Probability of dying at time t
Length-weight relationship $W_t = \beta_3 L_t^{\beta_4}$	Wt: Weight of fish (g) at time t. Tilapia: β_3=0.0015; β_4=3.077. Catfish: β_3=0.0073; β_4=2.99 Snakehead: β_3=0.0059; β_4=3.008
Natural mortality rate: $M_{w,t} = M_u \beta_3^{-0.3} L_t^{-0.3\beta_4}$.	$M_{w,t}$: Natural mortality at weight W_t M_u : Natural mortality at unit weight Tilapia: M_u =1.0. Catfish: M_u =4.5. Snakehead: M_u =4.5
Predation relation [b]: $P_{p,t} = \beta_5 D_t L_t^{-\beta_6}$.	$P_{d,t}$: Tilapia mortality due to predation at time at time t. D_t : Predators density Catfish: β_5=280; β_6=1.5 Snakehead: β_5=1600; β_6=1.5

[a] The length at first maturity is 12.5 cm and recruitment in the model is constant and set at 0.3 mature female/day. The average fingerling production per female is between 200 and 300 per female per months assuming a mortality rate of 60% between larvae and fingerlings.

[b] In the model, catfish and snakehead only prey on Nile tilapia in the range of 0.8 – 10 cm as African catfish and snakehead can consume up to about 10% of its own body weight. The piscivorous behaviors of catfish and snakehead begin when they reach weight of 7–8 g.

Table 2: Von Bertalanffy Growth Constant and Maximum Length by Feeding Levels.

Parameter	Sex, species	Low level	High level
L_∞	Male tilapia	32.50	32.50
	Female tilapia	23.00	23.00
	Catfish	120.00	120.00
	Snakehead	87.00	87.00
K	Male tilapia	1.37	1.72
	Female tilapia	1.02	1.29
	Catfish	0.31	0.40
	Snakehead	0.65	0.65

the best management options based on cash flow and economic profitability of each option. Calibration and validation of the model was used to analyze the economic viability of smallholder aquaculture enterprise in Ghana, Kenya, and Tanzania.

Table 3 shows pond management and economic variables that were used to stimulate the model. Weight and length at stocking are based on the on-station research recommendations and literature review. The value of land is based on the opportunity cost of not producing maize on the plot allocated to fish farming. Maize is an important crop in areas that are also potential for aquaculture operation. The Food and Agricultural Organization (FAO) crop production database shows that in 2004, maize yield was about 1.5 ton/ha in Kenya, 1.49 ton/ha in Ghana, and 1.7 ton/ha in Tanzania. The producer price was 10,340 Kshs/ton in Kenya, 1.07 million Cedis/ton in Ghana, and 120,000 Tshs/ton in Tanzania. The opportunity cost of land is the lost revenue from maize production, i.e., 204,000 Kshs/ha in Kenya, 1.6 million Cedis/ha in Ghana and 204,000 Tshs/ha in Tanzania. The cost of pond construction is based on the market value. Private contractors, who use heavy equipments to construct fishponds, charge between 20,000 Kshs/100 m^2 (or 2 million Kshs/ha) in Kenya, and 20,000 Tshs/100m^2 (or 2 million Tshs/ha) in Tanzania. In Ghana, the cost of pond construction is estimated by multiplying the required 1,976 man-days equivalent to construct a 1 ha pond (Agyenim-Boateng et al., 1990) to the minimum wage of 12,200 Cedis/day. Maintenance and depreciation cost item is based on 10% of the pond construction cost and equipment cost. The equipment cost items include value of fishing gears, feeding and maintenance equipments specifically for pond operation that were owned by sample households. On average, the value of owned equipments was about 1–3% of the pond construction cost.

From the Kenya and Tanzania survey, the respondents indicated that in each household, there was one person responsible for managing the fishponds. The management included maintaining the pond, feeding, harvesting, and marketing the fish. It was estimated that the pond manager spends about 5% of the yearly full-time equivalent of about 2,080 hours to manage a 200 m^2 fishpond. Cost per day is calculated from the minimum wage set by the government at 4,279 Kshs/month in Kenya and 48,000 Tshs/month in Tanzania. Apart from supplementing natural food in ponds, Liti et al. (2005) showed that high protein feed supplementation was important for fish weighing more that 140 g. The farmers in the sample used mostly maize bran and manure to feed the fish and fertilize the ponds at an average rate of 9 tons per ha. They also used kitchen leftovers and leaves that are assumed to have a marginal cost of zero. The crude protein of maize and rice bran was set at 12.5% (Muir and Massaete, 1996). Hotland (1993) showed that nitrogen content of cow manure is about 2.5%. In Kenya, a 50 kg of ammonium nitrate bag with 50% nitrogen was sold at 1,846 Kshs or 74 Kshs per 1% of nitrogen (i.e., 185 Kshs/kg of manure). In Tanzania, a 50 kg of ammonium nitrate bag with 50% nitrogen was sold at 8,000 Tshs or 320 Tshs per 1% of nitrogen (i.e., 800 Tshs/kg of manure). In Table 3, the price of maize bran and fish were estimated from the survey data. In the analysis, mode was preferred to the mean as it included costs and prices that were incurred by majority of respondents.

Table 3: Data Input on Pond Management and Economic Variables for Base Case.

Variable		Kenya Values	Ghana Values	Tanzania Values
Pond characteristics				
Area of ponds		$200m^2$, $634m^2$	$2000m^2$, $4000m^2$	$150m^2$, $300m^2$
Weight at stocking	Tilapia	20g	20g	20g
	Catfish	30g	30g	30g
Density stocked	Tilapia	$2/m^2$	$2/m^2$	$2/m^2$
	Catfish	$0.2/m^2$	$0.2/m^2$	$0.2/m^2$
Economic variables [1]				
Fixed costs	Land [2]	15,640 Kshs/ha	1,599,283 Cedis/ha	204,000 Tshs/ha
	Pond construction	126,803 Kshs/$300m^2$	24,107,200 Cedis/$300m^2$	2,000,000 Tshs/$300m^2$
	Equipments	3,804 Kshs/ha	241,072 Cedis/ha	100,000 Tshs/ha
	Maintenance and depreciation (10%)	13,061	2,434,827	210,000
	Interest on capital (8%)	10,449	1,339,155	168,000
Variable costs	Labor [3]			
	Number of persons/ha/yr	0.08	0.34	0.05
	Cost per day	141 Kshs	12,200 Cedis	1,600 Tshs
	Feed			
	Manure	185 Kshs/kg	1,537 Cedis/kg	800 Kshs/kg
	Fertilizer		2,340 Cedis/kg	
	Maize bran	4 Kshs/kg	537 Cedis/kg	66 Kshs/kg
	Fish price at the farm level			
	Tilapia fingerlings	8 Kshs/kg	275 Cedis/kg	65 Kshs/kg
	Small tilapia fish	81 Kshs/kg	10,844 Cedis/kg	1,214 Kshs/kg
	Medium size tilapia	101 Kshs/kg	13,555 Cedis/kg	1,518 Kshs/kg
	Large size tilapia	121 Kshs/kg	17,731 Cedis/kg	1,925 Kshs/kg
	Catfish	125 Kshs/kg	18,001 Cedis/kg	2,000 Kshs/kg

[1] The exchange rate used was US $1 equals 76.85 Kshs, 1,166.70 Tshs, and 9,000.50 Cedis.

[2] The calculation is based on the opportunity cost of producing maize instead of fish based on the FAO 2004 database maize yield. In Kenya average was 1.5126 ton/ha and the producer price was 10,340 Kshs/ton; in Ghana it was 1.49 ton/ha and the producer price was 1,073,344 Cedis/ton; and in Tanzania, it was 1.7 ton/ha and the producer price was 134,420 Tshs/ton.

[3] It is estimated that one unskilled individual will spend 5% of the available time to manage the pond, which includes feed preparation/collection, feeding, harvesting and marketing. The cost is based on the minimum wage.

The labor required to manage a 4,000 m^2 pond in Ghana was estimated to be 35 man-days (Wijkstrom and Macpherson, 1990) or 87.5 man-days per year for a 1 ha pond. The available man-days equivalent is about 260 days or 2,080 hours for a person working a full-time job (average of 8 hours a day). A value of 0.33 translated into 2.7 hours part-time job for full year. That means that within a year, a fishpond manager will spend about 2.7 hours per day at the 1 ha pond for 260 days. Pond management included maintaining the pond, feeding, harvesting and marketing the fish. Cost per day is based on the minimum wage of 12,200 Cedis/day. The cost of manure is based on the cost of transporting and applying manure in the pond. The use of a 5-ton truck and application of manure in the pond costs the equivalent of 70 man-days equivalent per day of unskilled farm labor. About 9 tons of manure is needed to fertilize a 1 ha pond (Agyenim-Boateng et al., 1990). Equivalently, 126 man-days are need for manure transportation and application, costing about 1,537 Cedis/kg. Price of fertilizer, maize or rice bran and fish were estimated from the survey data.

RESULTS

The different Nile tilapia cultures were simulated based on combinations of fish population dynamics and economic variables presented in Tables 1 and 2, and pond management and economic variables in Table 3. The results are presented in Tables 4 through 6.

Kenya

Table 4 presents the results for a 200 m^2 and a 634 m^2 pond. In the a 200 m^2 pond, total annual cost per pound of fish harvested was 51 Kshs for mixed-sex tilapia culture without catfish predation, 58 Kshs for mixed-sex tilapia culture with catfish predation, and 46 Kshs for hand-sexed all male tilapia culture. The results show an increase in unit cost from mixed-sex tilapia culture without predation to mixed-sex tilapia culture with predation, and a decrease in unit production cost from polyculture to monoculture. Feed cost was between 6% and 18%. Cost of fingerlings accounted for more than 80% of the total cost. Operational expenses accounted for less than 12% of the total cost. Management techniques to reduce fingerling costs may have the highest impact on cost reduction in the farming system. Due to difference in fish growth in ponds, which results from competition and predation, different sizes of fish were harvested (i.e., large, medium, small fish). Annual sale was 5,845 Kshs for the mixed-sex tilapia culture without predation, 8,018 Kshs for mixed-sex tilapia culture with catfish predation, and 10,919 for hand-sexed all male tilapia culture (Table 4). Revenue was mainly from small-sized fish for mixed-sex tilapia culture without predation (81%), similar to the mixed-sex tilapia culture with catfish predation (58%). Catfish contributed about 28% of the total revenue in the second culture. For the hand-sexed all male tilapia culture, 88% of the revenue came from larger tilapia and the small fish contributed only 2%. The medium size tilapia contributed about 10% of the total revenue. The estimated total revenue and cost generated about 2,701 Kshs in annual profit for mixed-sex tilapia culture, 3,412 Kshs for the mixed-sex tilapia and 6,645 Kshs for hand-sexed all male tilapia culture. The results indicate higher returns for each Kshs invested in the monoculture production system.

Annual costs were 13,117 Kshs (mixed-sex tilapia without predation), 14,573 Kshs (mixed-sex tilapia with predation), and 15,652 Kshs (hand-sexed all male tilapia) for a 634 m^2 pond (Table 4). Feed constituted between 5 and 8% of the annual total cost. Unit cost per a kg of fish produced was 68 Kshs for mixed-sex tilapia with predation, 60 Kshs for mixed-sex tilapia culture without predation, and 50 Kshs for hand-sexed all male tilapia culture. The results indicate a decrease in unit cost from mixed-sex to monoculture. Annual sales were 16,209 Kshs for the mixed-sex tilapia culture without predation, 25,092 Kshs for mixed-sex tilapia culture with catfish predation, and 30,645 for hand-sexed all male tilapia (Table 4). Again, revenue was mainly from small-sized fish for mixed-sex tilapia culture without predation (94%), and mixed-sex tilapia culture with catfish predation (60%). Catfish contributed about 26% of the total revenue in the second culture. For hand-sexed all male tilapia culture, 51% of the revenue came from larger tilapia and the small fish contributed only 26%. The medium size tilapia contributed about 23% of the total revenue. The

Table 4: Results of Economic Analysis for Kenya.

		200m² pond		634m² pond	
Variable/culture[a]		**Quantity (kg)**	**Amount (Kshs)**	**Quantity (kg)**	**Amount (Kshs)**
Mixed-sex tilapia without predation					
Costs	Feed		233		721
	Fish		2,520		11,158
	Operational		391		1,238
	Total		**3,144**		**13,117**
Revenue	Large tilapia	2	277	5	663
	Medium tilapia	8	818	28	284
	Small tilapia	52	4,750	160	15,262
	Total	**62**	**5,845**	**193**	**16,209**
Profit			**2,701**		**3,092**
Mixed-sex tilapia with catfish predation					
Costs	Feed		295		909
	Fish		3,920		12,426
	Operational		391		1,238
	Total		**4,606**		**14,573**
Revenue	Large tilapia	3	385	6	737
	Medium tilapia	8	776	29	2,986
	Small tilapia	50	4,630	158	14,963
	Catfish	18	2,227	51	6,406
	Total	**76**	**7,633**	**238**	**24,355**
Profit			**3,027**		**9,782**
Hand-sexed all male tilapia[b]					
Costs	Feed		346		1,011
	Fish		3,520		11,158
	Operational		408		1,294
	Total		**4,274**		**13,463**
Revenue	Large tilapia	79	9,615	129	15,652
	Medium tilapia	11	1,140	70	7,113
	Small tilapia	2	164	72	7,880
	Total	**92**	**10,919**	**271**	**30,645**
Profit			**6,645**		**17,182**

[a] With a maximum of 300 rearing days.
[b] A 5% marginal of error is allowed.

estimated total revenue and cost generated about 3,092 Kshs in annual profit for mixed-sex tilapia culture without predation. Annual profits for the mixed-sex tilapia and hand-sexed all male tilapia cultures 24,392 and 30,645 Kshs, respectively (Table 4). While costs were relatively similar for mixed tilapia culture without predation and hand-sexed all male tilapia culture, the revenue was significantly higher (about 2 fold) for hand-sexed all male tilapia culture.

Tanzania

Table 5 presents the results for a 150 m^2 pond and 300 m^2 pond. For a 150 m^2 pond, ownership and operating costs generated total annual cost of 45,046 Tshs for a mixed-sex tilapia culture without catfish predation. For mixed-sex tilapia culture with catfish predation and hand-sexed all male tilapia culture, total annual costs were respectively, 54,988 and 54,970 Tshs. There was no significant increase in cost from one tilapia culture to another. Total annual cost per pound of fish harvested (total cost/quantity) was 1,073 for mixed-sex tilapia culture without catfish predation, 1,000 Tshs for mixed-sex tilapia culture with catfish predation, and 887 Tshs for hand-sexed all male tilapia culture. The results show a decrease in unit cost from mixed-sex cultures to monoculture. In all cases, feed cost was over 55% of the total cost about 600 Tshs per kg of fish produced. Cost of fingerlings accounted for 33% to 37% of the total cost. Operational expenses accounted for less than 8% of the total cost. Management techniques to reduce feed and fingerling costs may have the highest economic benefit in the aquaculture farming system. Annual sale was 46,152 Tshs for the mixed-sex tilapia culture without predation, 75,231 Tshs for mixed-sex tilapia culture with catfish predation, and 103,586 Tshs for hand-sexed all male tilapia culture (Table 5). Revenue was mainly from small-sized fish for mixed-sex tilapia culture without predation (79%), and mixed-sex tilapia culture with catfish predation (50%). Catfish contributed about 36% of the total revenue in the second culture. For the hand-sexed all male tilapia culture, 60% of the revenue came from larger tilapia and the small fish contributed only 16%. The medium tilapia contributed about 24% of the total revenue. The estimated total revenue and cost generated about 1,106 Tshs in annual profit for mixed-sex tilapia culture. Annual profits for the mixed-sex tilapia and hand-sexed all male tilapia cultures were 20,261 Tshs and 48,616 Tshs, respectively; showing higher returns for the monoculture production system.

For a 300 m^2 pond, the annual costs were 91,724 Tshs (mixed-sex tilapia without predation), 108,741 Tshs (mixed-sex tilapia with predation), and 129,446 Tshs (hand-sexed all male tilapia). Feed comprised between 54% and 60% of the annual total cost. Unit cost per kg of fish produced was 1,079 Tshs for mixed-sex tilapia without predation, 1,026 Tshs for mixed-sex tilapia culture without predation, and 1,227 Tshs for hand-sexed all male tilapia culture. These results do not show any specific trend when compared to the results of the 150 m^2 pond. Annual sales for each culture were 95,791 Tshs for the mixed-sex tilapia culture without predation, 141,734 Tshs for mixed-sex tilapia culture with catfish predation, and 185,559 for hand-sexed all male tilapia (Table 5). Revenue was mainly from small sized fish for mixed-sex tilapia culture without predation (74%), and for mixed-sex tilapia culture with catfish predation, 52%. Catfish contributed about 33% of the total revenue in the second culture. For hand-sexed all male tilapia culture, 52% of the revenue came from larger for mixed-sex tilapia culture without predation. Annual profits for the mixed-sex tilapia and hand-sexed all male tilapia cultures were 32,993 Tshs and 56,013 Tshs, respectively (Table 5).

Ghana

Two Nile tilapia cultures were simulated based on combinations of fish population dynamics and the economic variables presented in Tables 1 through 3. Table 6 presents the results for 2,000 m^2 pond as well as a 4,000 m^2 pond. For a 2,000 m^2 pond, ownership and annual costs generated total value of about 6.2 million Cedis for a mixed-sex tilapia culture with catfish predation. For hand-sexed all male tilapia culture, total cost was 7.1 million Cedis, a 13% increase in production cost. tilapia and the small fish contributed only 19%. The medium tilapia fish contributed about 29% of the total revenue. The estimated total revenue and cost generated about 4,067 Tshs in annual profit Total annual unit cost per pound of fish harvested was 8,596 Cedis for mixed-sex tilapia culture with catfish predation and 8,047 Cedis for hand-sexed all male tilapia culture, which is about a 6%

decrease in production cost. In both cultures, feed cost was over 58% of the total cost or more than 4,997 Cedis per kg of fish produced. Cost of fingerlings accounted for 12% to 17% of the total cost.

Table 5. Results of Economic Analysis for Tanzania.

		150m^2 pond		300m^2 pond	
Variable/culture[a]		**Quantity (kg)**	**Amount (Tshs)**	**Quantity (kg)**	**Amount (Tshs)**
Mixed-sex tilapia without predation					
Costs	Feed		24,923		51,478
	Fish		16,500		33,000
	Operational		3,623		7,246
	Total		**45,046**		**91,724**
Revenue	Large tilapia	1	2,426	2	4,560
	Medium tilapia	5	7,267	14	20,563
	Small tilapia	36	36,459	69	70,668
	Total	**42**	**46,152**	**85**	**95,791**
Profit			**1,106**		**4,067**
Mixed-sex tilapia with catfish predation					
Costs	Feed		33,065		64,895
	Fish		18,300		36,600
	Operational		3,623		7,246
	Total		**54,988**		**108,741**
Revenue	Large tilapia	2	3,517	1	2,475
	Medium tilapia	5	7,419	12	18,548
	Small tilapia	34	37,280	70	73,959
	Catfish	14	27,015	23	46,752
	Total	**55**	**75,231**	**106**	**141,734**
Profit			**20,243**		**32,993**
Hand-sexed all male tilapia [b]					
Costs	Feed		33,047		69,600
	Fish		18,300		52,800
	Operational		3,623		7,246
	Total		**54,970**		**129,646**
Revenue	Large tilapia	32	62,409	50	95,986
	Medium tilapia	16	24,789	36	54,395
	Small tilapia	14	16,388	29	35,278
	Total	**62**	**103,586**	**115**	**185,659**
Profit			**48,616**		**56,013**

[a] With a maximum of 300 rearing days.
[b] A 5% marginal of error is allowed.

Operational expenses accounted for 21% of the total cost in both cultures (Table 6). Management technique to reduce feeding cost may have the highest impact on cost reduction in both tilapia cultures.

For a 2,000 m^2 pond, annual revenue was about 8.4 million Cedis for the mixed-sex tilapia culture with predation and 13.1 million Cedis for hand-sexed all male tilapia culture. Revenue was mainly from small-sized fish (49%) and catfish (36%) for mixed-sex tilapia culture with predation (79%). For the hand-sexed all male tilapia culture, 59% of the revenue came from larger tilapia, and the medium size fish contributed 24%. The small fish contributed only 17% of the total revenue. The estimated total revenue and cost generated about 2.2 million Cedis in annual gross profit for mixed-sex tilapia culture. Annual profit for all male tilapia culture was about 6.0 million Cedis. The profit is more than two fold when compared to polyculture.

For a 4,000 m^2 pond, annual total costs were about 12.5 million Cedis for polyculture and 14.0 million Cedis for hand-sexed all male tilapia culture (Table 6). Unit cost per kg of fish produced was 8,631 Cedis for polyculture and 7,930 Cedis for the hand-sexed all male tilapia culture, which is a 10% reduction in a unit production cost. Feed contributed more than 58% of the total cost. Annual total revenue for polyculture was about 16.8 million Cedis and 25.0 million for the hand-sexed all male tilapia. Revenue was mainly from small-sized fish for polyculture (49%). Catfish contributed 36% of the total revenue for this culture. For the hand-sexed all male tilapia culture, 59% of the revenue came from larger tilapia and the small fish contributed only 17%. The medium tilapia fish contributed about 23% of the total revenue. The estimated total revenue and cost generated about 4.3 million Cedis in annual profit for polyculture. Annual profit for the all male tilapia culture was 12.1 million, which is about a 3-fold increase in profit over profits from polyculture (Table 6).

DISCUSSION

The results presented in Tables 4 through 6 clearly indicate that hand-sexed all male tilapia culture is superior to mixed-sex tilapia culture. The technology of sex separation or reversal in tilapia that is adaptable to rural Africa should be actively pursued. Sex-reversal is considered a high technology innovation, which may be economically unsustainable. However, with targeted capacity building, the technology can be simple and economically sustainable within rural aquaculture farming systems. In the interim however, mixed-sex tilapia culture with catfish predation could be improved with better production resources such as feed and quality fingerlings because the results showed it performed better economically than mixed-sex tilapia culture without predation for the different pond sizes in both Kenya and Tanzania. Moreover, the results showed there was no significant increase in cost after introducing catfish predation in mixed-sex culture from mixed-sex culture without catfish predation.

Rural aquaculture lacks investment mainly because of the absence of quality economic data and analysis. The information provided in Tables 4 through 6 are the type of information needed for the preparation of enterprise budgets and business plans to secure the needed financial assistance and support for investments and development. From Table 4, the realized gross profit margins in Kenya of more than 45% for a 200 m^2 pond and more than 19% for a 634 m^2 pond are high enough to attract investment in aquaculture through borrowed capital. With the exception of mixed tilapia without predation in the 634 m^2 pond, the realized gross profit margins were more than 40%. The same could be said of aquaculture in Ghana, where the realized gross profit margins were more than 35% for monoculture. All male tilapia production increased gross profit margin from 26% to 39% for a 2,000 m^2 pond, and from 26% to 46% for a 4,000 m^2 pond. Such high margins should appeal to lending institutions. In Tanzania, raising hand-sexed all male tilapia increased gross profit margin to 47% and 30% for 150 m^2 pond and 300 m^2 pond, respectively. High margins are also beneficial in limiting the effects of price volatility, which is common in sub-Saharan Africa. In Ghana, for example, results from the polyculture system showed that prices of fish have to fall by more than 26% for a loss to occur.

Table 6. Results of Economic Analysis for Ghana.

		2,000m^2 pond		4,000m^2 pond	
Variable/culture[a]		**Quantity (kg)**	**Amount (Cedis)**	**Quantity (kg)**	**Amount (Cedis)**
Mixed-sex tilapia with catfish predation					
Costs	Feed		3,637,954		7,232,761
	Fish		1,330,000		2,660,000
	Operational		1,289,863		2,579,725
	Total		**6,257,817**		**12,472,486**
Revenue	Large tilapia	14	239,515	23	403,708
	Medium tilapia	77	1,037,089	153	2,075,922
	Small tilapia	468	4,130,731	934	8,304,749
	Catfish	169	3,035,619	335	6,033,397
	Total	**728**	**8,442,954**	**1,445**	**16,817,776**
Profit			**2,185,137**		**4,345,290**
Hand-sexed all male tilapia[b]					
Costs	Feed		4,397,459		8,798,124
	Fish		1,210,000		2,420,000
	Operational		1,465,753		2,731,506
	Total		**7,073,212**		**13,949,630**
Revenue	Large tilapia	436	7,725,214	866	15,349,962
	Medium tilapia	229	3,106,697	449	6,084,349
	Small tilapia	214	2,213,435	444	4,543,880
	Total	**879**	**13,045,346**	**1,759**	**25,978,191**
Profit			**5,972,134**		**12,028,561**

[a] With a maximum of 300 rearing days.
[b] A 5% marginal of error is allowed.

Cost changes associated with the different farm sizes reveal some important economic patterns in African rural aquaculture production. In Kenya, all scenarios of moving from a 200 m^2 pond to a 634 m^2 pond were accompanied by about three-fold increase in revenue and production costs (Table 4). The pattern is similar regarding the results on quantities of fish produced. This is an indication of constant returns to scale. The most adopted pond size of 200 m^2 may be too small to be economically efficient. The mean pond size of 634 m^2 may not be optimal. In Tanzania, moving from a 150 m^2 pond to a 300 m^2 pond was accompanied by doubling of production costs (Table 5). However, additional increase in revenues for the 300 m^2 pond is less than double when compared to revenue from a 150 m^2 pond. The pattern is similar regarding the results on quantities of fish produced. This may be an indication of decreasing economies of scale or decreasing return to scale. The advantage may arise from efficient management of smaller ponds than larger ponds. Research is required to determine optimal pond size for efficient use of resources.

Ghana had relatively larger pond sizes compared to Kenya and Tanzania. There was no significant increase in cost of production after introducing monoculture. In both tilapia cultures, moving from a 2,000 m^2 pond to a 4,000 m^2 pond was accompanied by doubling of production costs (Table 6). Additional increase in revenues for the 4,000 m^2 pond was more than double when compared to revenue from the 2,000 m^2 pond. There was also an increase in the quantities of fish produced from the two pond sizes. It suggests that it will be more profitable to operate a 4,000 m^2 pond than operating a 2,000 m^2 pond, an indication of increasing returns to scale. Operational expenses in Ghana were relatively equal in the two culture systems. Since operational expenses include family labor, an aquaculture production system that is based on the production of Nile tilapia should be more concerned with availability of feed at affordable price and supply of quality fingerlings.

CONCLUSIONS

In this study a dynamic economic model was used to analyze the profitability of various Nile tilapia production culture types that included mixed-sex without predation, mixed-sex with catfish predation, and hand-sexed all male tilapia. In general, the results suggest that the commonly practiced mixed-sex tilapia culture, though economically feasible and profitable, was inferior to all male tilapia cultures in terms of economic viability. Research and extension efforts are required to develop sex separation or reversal in Nile tilapia that are adaptable by rural farmers. Switching from polyculture and no predation to predation culture did not add significant amounts of operational costs. Pond size played a significant role in the economic viability of aquaculture enterprises due to economies of scale and suggests research into optimal pond sizes. The study provided information needed for the preparation of enterprise budgets and business plans that can be used to secure needed financial assistance and support for investments and development. Realized gross profit margins from monoculture of all male tilapia are high enough to attract investment in aquaculture through borrowed capital. Success of developing an economically sustainable Nile tilapia production system also depends on developing affordable feeds and efficient quality fingerling supply system. The use of quality feed and fingerling will ensure the production of larger and quality fish that attracts higher price at the farm level.

ANTICIPATED BENEFITS

Results from the study will enable an assessment of investment requirements and operation costs to generate reference economic information that is useful to new entrepreneurs and existing aquaculture farms. Results will also provide important first step analytical information on production economics in rural Africa. This information will assist fish farmers in evaluating the profitability of fish-farming ventures, and will provide information on issues such as risks, costs, finance, and policy as they relate to rural aquaculture enterprises. This will be a useful tool for improved decision-making by non-governmental as well as governmental agencies for funding aquaculture development projects.

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A CROSS-NATIONAL ANALYSIS OF THE POTENTIAL ECONOMIC IMPACT OF AQUACULTURE IN AFRICA

Eleventh Work Plan, Economic/Risk Assessment and Social Analysis 4 (11ERA4)
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ABSTRACT

There is increased interest and policy support towards aquaculture development in Africa. Aquaculture development programs have the potential of creating new jobs, improving food security among poor households, removing variability in household income flow, and increasing farm level efficiency and sustainability. This study used computable general equilibrium models for Ghana, Kenya, and Tanzania to estimate the effects on poverty alleviation from aquaculture production activity and productivity growth in intermediate inputs and primary factors. Using the head count ratio measure of poverty, it was determined that, in Ghana, about 17% of agricultural farmers lived below the poverty line, and about 19% of public sector employees lived below the poverty line of 665,300 GHC. The percentages for the private sector employee, non-farm self-employed and miscellaneous households were, respectively, 8%, 21%, and 20%. In Kenya, more than 50% of the population lived below the poverty line of 14,868 KES in 2001. The most affected were female-headed households in rural areas. In Tanzania, 38% of rural households, and 23% of urban households lived below the poverty line. With aquaculture expansion, the general results of the study suggest that there will be positive effects in per capita income for all households in Ghana and Kenya. In Tanzania, some rich households will experience income loss due to resource shift from the fisheries and manufacturing sectors to aquaculture. The measure of poverty gap decreased in all households groups in all countries with aquaculture expansion. This was the result of decreases in poverty lines associated with decreases in relative price, and increases in the minimum income associated with income expansion. Sectoral-linkages incorporated in the models suggest that, aquaculture development is promising for sector-specific policy support to enhance poverty alleviation programs among poor households in Sub-Saharan Africa.

INTRODUCTION

Aquaculture in Sub-Saharan Africa is currently undergoing some growth with support from policy makers. A four-day summit in 2005 on the future of African fisheries in Abuja, Nigeria, organized under the auspices of the New Partnership for Africa's Development (NEPAD), was a culmination of aquaculture policy support in Sub-Saharan Africa. The Abuja Declaration on Sustainable Fisheries and Aquaculture called for increased fish production focusing more on aquaculture promotion and development. Aquaculture was observed to be the only logical means of increasing fish supply without depleting wild stocks and maintaining low priced fish affordable to poor households.

Aquaculture can be integrated into existing farming systems to enhance rural employment and income through additional and off-seasonal production activities, improved food security and nutrition, and decreased risk through diversification. Aquaculture can also improve water availability and nutrient recycling and environmental benefits through enhanced resource flows and sustainability (Tacon, 2001; Edwards, 2000). To have a noticeable impact in Sub-Saharan Africa, Muir et al. (2005) suggested that aquaculture has to grow by more than 10% annually in the next 15 years in order to meet projected demand and that annual production has to increase from about 700,000 metric tons to more than 3 million metric tons. This growth requires between \$1 to \$2 billion, and an annual additional investment of more than \$200 million (Muir et al., 2005). A well-planned aquaculture development program has great potential in terms of job creation, improved food security, smoothing household income flow, and increased farm level efficiency and sustainability.

Unemployment is a major concern for governments in Sub-Saharan Africa. Labor demand in many Sub-Saharan African countries is seasonal. Aquaculture enterprises can create new jobs and remove seasonality in labor demand. Employment opportunities are also possible on larger farms through job creation in activities such as seed supply networks, marketing chains and manufacturing, repair shops, and other aquaculture support services. Aquaculture can also benefit the landless through utilization of common resources, such as finfish cage and cove cultures, culture of mollusks and seaweeds, and fisheries enhancement in communal water bodies. For small-scale operations, women undertake many aquaculture activities that include marketing. Aquaculture can therefore provide part-time jobs to women who are the key managers of household resources directed at consumption. Empowerment of women encourages them to become further involved in the decision-making process and other development activities (Simba, 2001; Edwards, 2000).

Achieving food security is an important aspect of general development objectives such as poverty alleviation. Fish are a great source for protein and minerals, are low in saturated fats and a good source of essential fatty acids, which is a combination for good health. To be food secure, households and individuals need to have food available to them, have access to food, and have the ability to fully utilize the food once it is consumed (USAID 1995). Aquaculture can contribute to improved food security and nutrition through various channels. For example, local food supplies can be improved through increased availability of low-cost fish. Increasing the quantity and variety of fish and other foods consumed by the poor will reduce under-nutrition within rural communities (Tacon, 2001).

In Tanzania, Kenya, and Ghana there is a potential for increased aquaculture production activity and productivity growth in intermediate inputs and primary factors. Aquaculture expansion will involve increasing the number of fishponds and optimizing the use of available natural resources. Though pond culture is the main production system in most of Africa, there are possibilities for utilizing a wider range of production systems for fish farming such as cage culture, recirculating systems, raceways, and integrated aquaculture production systems. This paper examines the potential socio-economic impacts of aquaculture expansion in Africa using Tanzania, Kenya and Ghana as case studies.

The objectives of the study are:

1. To estimate the potential economic impact of small- and medium-scale aquaculture developments on community development.
2. To assess the impact of fish farming on rural poverty alleviation and food security.

MATERIALS AND METHODS

A proper assessment of the potential impacts of various sector (e.g., aquaculture) investments requires a comprehensive economic framework to analyze interactions and linkages between different sectors of the economy. In this paper, the computable general equilibrium (CGE) model is applied to Ghana, Kenya, and Tanzania in which the social accounting matrix (SAM) are benchmark datasets. The datasets were developed and used to assess the impacts of increased aquaculture production on poverty alleviation and food security among rural households. The three models are based on the standard neoclassical specification of trade-focused CGE models.

There are five major economic agents and three markets in the model. The economic agents include producers, households, government, firms, and rest of the world. The three markets are commodity market, factor market, and financial market. Income flow among economic agents is channeled through factor and commodity markets. The commodity market is the medium of exchange for domestically produced goods and imports, which are purchased as intermediate inputs by producers and final demand by households and the government. The factor market is the medium of exchange for wages and capital rents to households and firms. The financial market acts as a reserve for savings collected from households and rest of the world and disbursed in the form of investment to the commodity market. The basic model simulates a market economy where prices and quantities adjust to clear commodity, factor, and financial markets in the models.

The potential impact of aquaculture expansion in the selected countries is achieved through simulating the models to account for possible aquaculture production activity and productivity growth in intermediate inputs and primary factors mainly capital and labor that are used in aquaculture production. Changes in household incomes are then used to estimate the number of households that move out of poverty. The objective is to use these case studies of Ghana, Kenya, and Tanzania to demonstrate and quantify aquaculture's potential for alleviating poverty and to improve food security in Sub-Saharan Africa.

Computable general equilibrium (CGE) models

CGE models are usually built based on SAM data (Cohen, 1988). A SAM is the baseline data that contains a static account for all economic transactions taking place in a base year, presented in a square matrix form. The rows of the SAM contain receipts accounts of production activities, factors of production, institutions (households, government, and firms), investment and saving, import and export that account for purchased inputs for production activities, and commodities for consumption. The column elements represent expenditures made by these accounts. The matrix tracks how national outputs are produced and how household income is generated and distributed (Kehoe, 1996). Techniques for formulating SAM-CGE based models are detailed in Abbink et al. (1995). Löfgren et al. (2001) presents a procedure for constructing an algebraic standard CGE model in the General Algebra Modeling System (GAMS) Software (Brooke et al., 1992). Rutherford presents a simplified implementation of the same model using GAMS/MPSGE (Rutherford, 1998). A non-technical discussion of a basic CGE model for developing economies can be found in Wahrheim and Wobst (2005).

The CGE modeling transforms a SAM into an economy-wide model without extensive supplementary data while focusing on the demand side of the economy. This is achieved by simulating the working of a market economy in which prices and quantities adjust to clear all markets (Vargas et al., 1999). In its mathematical form, the CGE models contain a system of simultaneous equations divided into four blocks (i.e., price, production and trade, institution, and the economic system constraint). The price block consists of equations in which endogenous model prices are linked to other prices (endogenous or exogenous) and non-price model variables. The production block covers domestic production and input use; allocation of domestic output to home consumption, the domestic market, and export, the aggregation of supply to the domestic market; and the definition of the demand for trade inputs that is generated by the distribution process. The institution block has equations that define distribution of income to factor of production and owners of factor of production, intra-institutional transfers, household consumption expenditures on both domestically produced and imported commodities, investment demand and savings, and government expenditures. The fourth block contains equations that balance the market for factors of production, the market for commodities (demanded equals supply), and government revenue equals expenditure (Abbink et al., 1995).

The underlying principle for CGE models is that prices and production or demands for factors of production are determined within the economic system. At equilibrium, four major market characteristics must be fulfilled. First, the total market demand equals the total market supply for every factor and output. Second, prices are set so that equilibrium profits of firm are zero with all rents accruing to factors. Third, household incomes equal household expenditures. Fourth, government tax revenues equal government expenditures that include subsidy payments. Thus, the CGE model contains a complete specification of the optimization problems facing all actors in the economy. This makes it possible to trace all results of the model to specific agents in the economy (Bautista et al., 1999).

Poverty analysis in a CGE framework

Various definitions and concepts exist for what constitutes poverty. This study focuses on what is typically referred to as incidence of poverty and poverty vulnerability. Incidence of poverty indicates whether a household possesses enough resources or abilities to meet their current needs. This definition is based on a comparison of household income or consumption with some defined threshold below which households are considered as being poor in that particular attribute. Two steps are involved in the measure of incidence of poverty. The first step involves estimating the poverty equivalent scale or welfare measure. The second step involves estimating the poverty line. The standard means of determining whether a household is poor involves a comparison of its estimated poverty equivalent scale to a poverty line.

In the literature, there are two kinds of poverty lines. One is an absolute poverty line and the other is a relative poverty line. The absolute poverty line is based on a basket of quantities of commodities reflecting basic needs or minimum consumption requirements for each individual member of the population (Ravallion, 1994). With this approach, the value of the basket is determined using prevailing price, which is used to estimate a minimum per capita income poverty line. Relative poverty lines are used to define the poor relative to the average living standards in a given country. A relative poverty line is determined in relation to a certain percentage of the mean, mode or median of per capita expenditure or income within the country. For example, it may be determined that households receiving less than 50% of the median per capital income are poor. Although the minimum basket of goods may remain the same, both lines are not fixed, as the monetary value of the basket will change with inflation and the relative poverty line will change with average expenditure or income levels (Decaluwé et al., 1991).

Poverty vulnerability is the probability of an individual or household falling below the poverty line in the near future, i.e., the probability or risk today of being in poverty or falling deeper into poverty at some point in the future. Vulnerability is a key dimension of poverty, since it affects households' behavior in terms of investment, production patterns, and coping strategies and their perception of their own situation. Therefore, poverty vulnerability is a stochastic dimension of poverty. Whereas incidence of poverty measures ex-ante poverty (poverty alleviation), vulnerability to poverty is an ex-post concept (measures impact of poverty alleviation programs).

The most popular money-metric measure for incidences of poverty is that of Foster et al. (1984) defined as:

$$P_\rho = \int_{y_{\min}}^{z} \left[\frac{z - y_i}{z}\right]^\rho \approx \frac{1}{N}\sum_{i=1}^{M}\left[\frac{z - y_i}{z}\right]^\rho . \tag{1}$$

In equation (1), z is the poverty line or poverty threshold, and ρ is the poverty aversion parameter or a measure of inequality parameter, y_i is the welfare measure by group i, N is the number of people in the sample population, and M is the number of poor people in the group. When $\rho = 0$, equation (1) reduces to M/N, the number of poor people in the population divided by the number of people in the sample population. When $\rho = 1$, the measure shows the deficit of the poor people from the poverty line (i.e., poverty gap index) and is used as an indicator of the minimum cost of eliminating poverty using perfectly targeted transfers. When $\rho = 2$, the index measures the severity (or intensity) of poverty and gives more weight to the poorest of the poor. The welfare measure of poverty (P_ρ) is also known as the headcount ratio when turned into a percentage (Decaluwé et al., 1999). A percentage change in a poverty gap is a crude measure of changes in poverty vulnerability.

In 1999, the monetary poverty line for Ghana was 665,300 GHC (or \$261) per person per year (Bhasin and Annim, 2005). The line was calculated from a consumption basket for the bottom 20% based on the national consumption distribution. The basket provided 2,900 kilocalories per adult equivalent per day. The basket contained all final demanded good in the economy. In Kenya, poverty lines are calculated based on various participatory poverty assessment (PPA) surveys conducted occasionally. In the PPA survey conducted in 2001, poverty was invariably associated with inability to meet certain basic needs. Quantitatively, the poverty line was estimated to be 1,239 KES per month per person or 14,868 KES (or \$189) per person per year (Mariara and Ndege 2004).

The Tanzania National Bureau of Statistics (NBS) uses two poverty lines to assess poverty levels; the food poverty line and the basic need poverty line. Both lines are determined from the household budget survey data using the reported consumption pattern by the second quintile of the sample population. To account for household consumption of other non-food items, the basic need poverty line is calculated by adding 25% of the within group expenditure on non-food items. For 2001, the food poverty lines were, respectively, 5,607 Tshs/28 days and 5,107 Tshs/28 days in urban and rural areas. The analogous values for the basic need poverty lines were 7,680 Tshs/28 days or 99,566 Tshs/year and 6,996 Tshs/28 days or 90,948 Tshs/year for urban and rural areas, respectively (NBS, 2004).

The poverty lines developed in respective countries were adopted for the poverty analyses. The basic need poverty line is determined by a basket of quantities of commodities reflecting basic needs. The monetary value of the poverty line is obtained by multiplying the basic needs basket by their respective prices and aggregated across commodities. The commodity prices are endogenously determined within the model, so is the monetary value of the line. The base year monetary value of the basic need basket is the proportion of total household expenditure. By letting the basic need basket remain invariant, it can be shown that the poverty line after the model simulation is:

$$P_s Q_b = P_0 Q_b \left[P_s Q_0 / P_0 Q_0 \right] = P_{b0} Q_b (RPI), \tag{2}$$

where P_s is the price index of commodities after the model simulation, Q_b is the quantities of the basic needs basket, P_0 is price of all commodities, Q_0 is the quantities of all commodities consumed, P_0Q_b is poverty line before simulation, P_sQ_b is poverty line after simulation, and RPI is the Laspeyres price index. Equation (2) indicates that with a change in commodity prices following an external economic shock, the poverty line will shift. Increase (decrease) in commodity prices will shift the poverty line to the right (left) and poverty will increase (decrease).

Data and the structure of the CGE Models

The database of the models included SAMs for Ghana, Kenya, and Tanzania. The model has different base years and structures for each country. The Ghana SAM was modified from Bhasin and Annim (2005) and the base year is 2001. Kenya and Tanzania SAMs were obtained from the International Food Policy Research Institute and the base year is also 2001. The structure of the SAM is documented in Wobst and Schraven (2004) for Kenya, and Thurlow and Wobst (2003) for Tanzania.

Based on the original SAMs, the data were aggregated to levels consistent with the objectives of this study. This was achieved in two steps. The first step involved aggregating the original SAMs to create fewer accounts. For Ghana, the exercise resulted in a SAM constituting seven accounts: two accounts for activity and commodity accounts including agriculture, manufacturing, and services, and one account for factors of production disaggregated into labor and capital. The household account included five types of households: agricultural farmers, public sector employee, private sector employee, non-farm self-employed, and miscellaneous households that earned income from different sources. The other two accounts included investment and rest of the world.

The Kenya SAM had an addition of two accounts; the marketing margin and tax accounts. The activities were divided into crop production, livestock operation, fishing, manufacturing, and services. Households were divided into rural and urban groups. Each group has six representative households; three for female-headed households, and three for male-headed households constituting ultra-poor, poor and non-poor households. The factors of production were divided into wage labor - agricultural, wage labor - non-agricultural, capital - agricultural and capital non-agricultural.

Apart from the marketing margin and tax account, the Tanzania SAM has an additional account for the enterprise. The five primary factors associated with factor markets include subsistence factor, labor, agricultural capital, non-agricultural capital, and agricultural land. The subsistence factor is to account for household's subsistence production (Thurow and Wobst, 2003). Labor supply is divided into child, female, and male labor sub-groups. Child labor supply is for participants aged 10 to 14. Female and male labor supply is for participants aged above 14 years and grouped into those without formal education, with some primary education, with some secondary education, and completed secondary or higher education. The household account is divided into urban and rural households. In each category, households are organized into six groups that include households below the poverty line, between food and basic needs poverty lines, non-poor head with no education, non-poor head with some primary education, non-poor head with some secondary education, and non-poor head with completed secondary education.

In the original SAM, aquaculture is lumped together with the crop sector in the case of Ghana and the fishing sector in the case of Kenya and Tanzania. Consequently, the respective sectors in each country were split to create the aquaculture sector. Data for the aquaculture sector on production, exports, and imports were obtained from the Food and Agricultural Organization of the United Nations (FAO) database. Intermediate inputs demand, value added, household demand, and income distribution among households were estimated using data from a farm survey conducted in Ghana, Kenya, and Tanzania between January and April 2005. The marketing margins and tax payment were estimated using tax rates on outputs from the original SAM. Sub-matrices related to government and enterprise commodity demand, investment demand, and marketing margins were estimated using proportion techniques. To ovoid errors that may have been introduced in the new SAM, a cross entropy difference method was used to balance the new SAM (Robinson et al., 2001a,b; Golan et al., 1996).

Tables 1a to 1c present the balanced aggregated 2001 macro SAM for Ghana, Kenya, and Tanzania respectively, after creating the aquaculture sector. As shown in Table 1, a square SAM is balanced when the sum of rows equal the sum of columns to satisfy the zero profit and market clearing conditions. For example, in Table 1c, the activity column (A) represents expenditure by production activities, which shows that about 6 trillion Tshs was spent on intermediate inputs, 8 trillion Tshs was spent on factors of production, and the activities paid 21 billion in value added tax. The commodity column (C) shows that goods value at 12 trillion Tshs were marketed in the domestic market, and the retail and marketing cost was about 356 billion Tshs. The indirect tax on marketed output was 436 billion Tshs, and the value of import at CIF was about 2 trillion Tshs. The factor column (F) shows how the factor income was distributed to households (i.e., 2 trillion to enterprises, 5 trillion to households, 18 billion to government as factor income tax, and 25 billion as dividends to factors owned by foreigners). The enterprise income (column E) was distributed to households (2 trillion Tshs), 1 billion Tshs was paid to the government as dividend, and 96 billion Tshs was paid in form of enterprise or corporate taxes.

Table 1a: Structure and aggregate SAM for Ghana - 1999 [Trillion Ghana Cedi (GHC)].

	A	C	F	H	G	X	IN	Total
Activities (A)	-----	13,159	-----	-----	-----	-----	-----	**13,159**
Commodities (C)	5,480	-----	-----	3,346	1,309	4,550	901	**15,586**
Factors (F)	7,679	-----	-----	-----	-----	-----	-----	**7,679**
Households (H)	-----	-----	3,492	-----	30	-----	-----	**3,522**
Government (G)	-----	816	580	176	-----	518	-----	**2,089**
Savings/Investment (X)	-----	-----	551	1	750	-----	3,766	**5,068**
Rest of the world (IN)	-----	1,611	3,056	-----	-----	-----	-----	**4,667**
Total	**13,159**	**15,586**	**7,679**	**3,522**	**2,089**	**5,068**	**4,667**	

Source: Modified from Bhasin and Annin (2005).

Table 1b: Structure and aggregate SAM for Kenya - 2001 [Billion Kenya Shillings (KES)].

	A	C	M	F	H	T	G	X	IN	Total
Activities (A)	-----	1,621	-----	-----	136	-----	-----	-----	-----	**1,758**
Commodities (C)	985	-----	99	-----	556	-----	150	114	233	**2,138**
Marketing margins (M)	-----	99	-----	-----	-----	-----	-----	-----	-----	**99**
Factors (F)	773	-----	-----	-----	-----	-----	-----	-----	-----	**773**
Households (H)	-----	-----	-----	773	-----	-----	37	-----	-----	**809**
Taxes (T)	-----	107	-----	-----	103	-----	-----	-----	-----	**210**
Government (G)	-----	-----	-----	-----	-----	210	-----	-----	-----	**210**
Saving/investment (X)	-----	-----	-----	-----	15	-----	23	-----	76	**114**
Rest of the world (IN)	-----	309	-----	-----	-----	-----	-----	-----	-----	**309**
Total	**1,758**	**2,138**	**99**	**773**	**809**	**210**	**210**	**114**	**309**	

Source: Adapted from Wobst and Scharaven (2004).

Columns H, which represents household expenditure, shows that goods valued at about 2 trillion Tshs were produced and consumed at home by households. Private household consumption was valued at about 5 trillion. The households paid 94 billion Tshs in income tax and households saving were 903 billion Tshs. The government column (G) indicates that the government paid for goods and services valued at 514 billion Tshs, distributed 61 billion as direct support to households, and saved about 91 billion Tshs. The government collected 666 billion Tshs in tax revenue (column TA). The trade column (TR) shows that commodities valued more than 1.3 trillion Tshs were exported. Households received 403 billion Tshs in the form of remittances from abroad. Foreign investment was about 324 billion Tshs. About 1.3 trillion Tshs was invested in the production of commodities (Column I). The data in the Ghana and Kenya SAMs has similar interpretation. The CGE models of all countries were developed following Devarajan et al. (1997). Each sector produces a composite commodity that is transformed according to a constant elasticity of transformation (CET) function into a commodity sold on the domestic market, consumed at home and exported. Output is according to a constant elasticity of substitution (CES) production function in primary factors and fixed input-output coefficients for intermediate inputs. Commodity produced for home consumption, private consumption, intermediate demand, enterprise, government, and investments are the five components of domestic demand. Consumer demand is based on Cobb-Douglas utility functions that generate fixed expenditure shares. Households pay income taxes to the government and save a fixed proportion of their income. Real government demand and real investment are fixed exogenously.

Table 1c: Structure and aggregate SAM for Tanzania - 2001 [Billion Tanzania Shillings (TZS)].

	A	C	M	F	H	E	G	T	X	IN	Total
Activities (A)	-----	11,989	-----	-----	1,932	-----	-----	-----	-----	-----	**13,921**
Commodities (C)	6,382	-----	355	-----	4,917	-----	511	-----	1,306	1,294	**14,765**
Marketing margins (M)	-----	355	-----	-----	-----	-----	-----	-----	-----	-----	**355**
Factors (F)	7,515	-----	-----	-----	-----	-----	-----	-----	-----	-----	**7,515**
Households (H)	-----	-----	-----	5,226	-----	2,150	61	-----	-----	399	**7,837**
Enterprise (E)	-----	-----	-----	2,245	-----	-----	-----	-----	-----	-----	**2,245**
Government (G)	-----	-----	-----	-----	-----	1	-----	662	-----	-----	**663**
Taxes (T)	24	432	-----	18	94	94	-----	-----	-----	-----	**662**
Saving/investment (X)	-----	-----	-----	-----	894	-----	91	-----	-----	321	**1,306**
Rest of the world (IN)	-----	1,988	-----	26	-----	-----	-----	-----	-----	-----	**2,014**
Total	**13,921**	**14,765**	**355**	**7,515**	**7,837**	**2,245**	**663**	**662**	**1,306**	**2,014**	

Source: Adapted from Thurlow and Wobst (2003).

There are three macro balances in the model: the government deficit, aggregate investment and savings, and the balance of trade. Government savings is the difference between revenue and spending, with real spending fixed exogenously, and revenue depending on a variety of tax instruments. Taxes include direct taxes on domestic institutions, import tariff, export taxes, value added or activity taxes, indirect or sale taxes, and factor taxes. The government deficit is therefore determined endogenously. Real investment is set exogenously and aggregate private savings is determined residually to achieve the nominal savings-investment balance. The balance of trade foreign savings are set exogenously and valued in world prices. The model solves for the relative domestic prices and factor returns that clear the factor and product markets. In equilibrium, there is exogenous aggregate trade balance in the model, and real exchange rate brings aggregate export supply and import demand into balance. The circular flow of income is captured by tracing the flow from producers to households, government, enterprises, and investors, and finally back to demand for goods and services in the product markets.

Model simulation or experimentation is focused on aquaculture production activity and productivity growth in intermediate inputs and primary factors. This is achieved by exogenously increasing the size of aquaculture production sector by 10%, and imposing productivity growth of intermediate inputs, labor and capital by 10%. To account for rigidities common in factors and commodity markets in developing countries, we used lower elasticities of substitution and transformations of supply and demand functions.

RESULTS AND DISCUSSION

Table 2 presents per capita income and consumption levels estimated in the original SAMs. In Table 2, the techniques for grouping households and thus income and consumption distribution were different for each country. In Ghana, household grouping is based on occupation, in Kenya, household grouping is based on gender and location, and in Tanzania, household grouping is based on education and location (rural or urban). However, while Kenyan data can be divided into female and male sub-groups the Tanzanian data cannot be divided into education sub-groups. Because of the differences in groupings, no comparison is done across the three countries.

In Ghana, on average, agricultural farmers had the highest per capita income and private sector employee has the lowest per capita income. However, the difference in average per capita income among Ghanaian households was not significantly high. Per capita income distribution in Kenya indicates that female-headed households had the lowest income compared to male-headed households. Incomes in rural areas were also lower when compared to incomes in urban areas. For Tanzania, rural income was lower than urban income and was more skewed to the left than urban income. Education has greatest influence on per capita income, especially in rural areas. There is a significant difference in per capita income between households where a head has primary education compared to the household where the head has a secondary education.

The data used for poverty analyses presented in Table 3 are based on the household groupings. Agricultural farmers in Ghana have the highest and lowest per capita income. Since the majority of farmers live in rural areas, this may be an indication of income gap within rural settings. While non-farm self-employed households showed the lowest maximum income among all household groups, it also showed the highest minimum income. The lowest income among non-farm self-employed households was about twice that of other household groups. Poorer households in non-farm self-employed household group were well-off when compared to poorer households in other household groups.

In Kenya, female-headed households in rural areas showed the lowest per capita minimum income and the lowest per capita maximum income. Both values are significantly lower when compared to other household groups. However, poorer female-headed households in urban areas were well-off when compared to poorer households in the male-headed group in rural areas. This probably explains the exodus of labor from rural to urban areas. The results for Tanzania showed a similar trend. In general, urban households are wealthier than rural households.

Table 3 also presents the estimated shape parameters of the beta distribution in equations (2) and (3). In a generalized beta distribution ($B[p,q]$), the parameters (p, q) jointly determine the shape and moments of the density function. If p and $q > 1$ and $p > q$, the distribution is skewed to the left. It suggests that there are more poor people than rich people. When q is relatively large compared to p, then, skewness to the left is more pronounced and the right-hand tail of the distribution is long, suggesting larger income disparity. Increase in p relative to q increases right skewness (more rich households) and increase in q relative to p increases left skewness (more poor households).

In Table 3, the estimated p parameter in all countries is close to 2, and the estimated q parameter is close to 6 suggesting that the majority of households in each group are in the lower quintiles of the income distribution. Except for the non-farm self-employed households, the estimated parameters are similar for Ghana suggesting that, despite the variability of income among household groups, the proportion of rich households is relatively equal in all household groups. Proportionally, there are fewer rich households in the non-farm self-employed household group (Table 3). Self-employment could be a way out of poverty for most households in Ghana. In Table 3, the shape of the probability density functions for Kenya is relatively similar for female-headed households, and male-headed households in rural and urban areas. However, skewness of the distribution to the left is relatively strong for male-headed households in urban areas suggesting that there are fewer households who are well-off in the female-headed household group in rural areas of Kenya. For Tanzania, the shape of the probability density function is also skewed to the left suggesting that, the average income will increase symmetrically with movement from rural to urban areas.

Table 2: Per Capita Income and Consumption of Economic Agents.

Country and Households		Number of individual[a]	Per capita income
Ghana [1999 Ghana Cedi ($1=3,420)]			
Agricultural farmers		9,854	2,765,729
Public sector employee		1,883	2,534,159
Private sector employee		1,582	2,206,560
Non-farm self employed		5,127	2,360,109
Miscellaneous households		1,582	2,398,446
	Total/Average	**20,028**	**2,994,932**
Kenya [2001 Kenya Shillings ($1=77.896 KES)]			
Rural female ultra-poor		2,896	6,814
Rural female poor		1,027	12,491
Rural female non poor		3,424	27,581
Rural Female		7,347	17,287
Rural male ultra-poor		5,814	9,929
Rural male poor '		2,476	17,752
Rural male non poor		8,020	36,897
Rural male		16,309	24,377
Urban female ultra-poor		139	9,799
Urban female poor		572	23,069
Urban female non poor		602	42,538
Urban female		1,314	30,585
Urban male ultra-poor		348	11,496
Urban male poor		2,496	16,310
Urban male non poor		2,838	70,412
Urban male		5,682	43,037
	Total	**30,652**	**26,403**
Tanzania [2001 Tanzania Shillings ($1=883.96 TZS)]			
Rural below food poverty line		5,081	76,578
Rural between basic needs poverty line		4,605	114,360
Rural non poor head with non education		3,512	208,015
Rural non poor head below primary school		3,500	237,625
Rural non poor head below secondary school		7,842	182,301
Rural non poor head finished secondary school		662	393,585
Rural households		25,202	165,383
Urban below food poverty line		675	58,683
Urban between basic needs poverty line		712	77,812
Urban non poor head with non education		423	152,130

Table 2 continued

Urban non poor head below primary school	689	206,902
Urban non poor head below secondary school	2,463	246,818
Urban non poor head finished secondary school	1,147	530,989
Urban households	6,109	248,604
Total	**31,311**	**181,620**

[a] Number in thousands.

Table 3: Data Used for Poverty Analyses.

County and Households		Income Bounds	
		Min	Max
Ghana			
Agricultural farmers		7,665	44,000,000
Public sector employee		13,808	39,000,000
Private sector employee		12,000	24,000,000
Non-farm self employed		23,865	24,000,000
Miscellaneous households		13,738	27,000,000
Kenya			
Rural Households	Female	1,246	37,579
	Male	1,769	197,902
Urban households	Female	1,889	211,094
	Male	2,119	684,815
Tanzania			
Rural households		5,144	1,514,029
Urban households		5,796	2,997,328

Table 4 presents the simulation results on percentage change in income for all countries with an expansion in aquaculture. Based on the structure of the CGE models, the percentage change in income is proportional to the percentage change in the Hicksian equivalent variation, i.e., households with positive percentage change in income will also have a positive percentage change in the Hicksian equivalent variation and vice versa. The results in Table 4 indicate a relative improvement in income for all household groups in Ghana (about 2%). This could be the result that all households groups in Ghana have some form of primary factors involved in aquaculture production. Exogenous aquaculture expansion and increased factor productivity will affect expansion of the production possibility curve of households and thus income.

For Kenya, improvement in income is relatively small. Large-scale agriculture and intensive farming in rural areas dominate the Kenya economy. There is also a well-established manufacturing sector in urban areas. Consequently, aquaculture expansion and increases in factor productivity did not significantly affect the relative price. In Tanzania, the impact of aquaculture expansion was mainly through labor movement from the fishing sector, and movement of non-agricultural capital from urban to rural areas. Income loss among non-poor households was associated with a decrease in labor income from the fishing sector.

Table 4: Simulation Results on Percentage Change in Household Income.

County and Households		Change in income
Ghana		
Agricultural farmers		1.900
Public sector employee		2.200
Private sector employee		2.200
Non-farm self employed		2.200
Non-working		2.200
	Average	**2.140**
Kenya		
Rural female ultra-poor		0.076
Rural female poor		0.091
Rural female non poor		0.012
Rural male ultra-poor		0.006
Rural male poor '		0.007
Rural male non poor		0.000
Urban female ultra-poor		0.002
Urban female poor		0.004
Urban female non poor		0.004
Urban male ultra-poor		0.001
Urban male poor		0.003
Urban male non poor		0.003
	Average	**0.017**
Tanzania		
Rural below food poverty line		3.700
Rural between basic needs poverty line		8.200
Rural non poor head with non education		-5.600
Rural non poor head below primary school		-6.800
Nonpoor head below secondary school		5.000
Rural non poor head finished secondary school		6.000
Urban below food poverty line		13.300
Urban between basic needs poverty line		18.200
Urban non poor head with non education		16.300
Urban non poor head below primary school		8.800
Nonpoor head below secondary school		9.400
Urban non poor head finished secondary school		-8.600
	Average	**5.658**

Table 5 presents the estimated poverty line or minimum income of household groups and poverty lines before and after the CGE model estimation. Table 5 also presents the estimated three poverty measures of the Foster-Greer-Thorbecke class before and after the CGE model simulation. The minimum incomes were obtained by substituting the poverty line variable in equation 2. In all countries, there is a slight increase in minimum income due to changes associated with labor movements within the household groups.

Using the head count ratio, it was determined that, in Ghana, about 17% of agricultural farmers lived below the poverty line, and about 19% of the public sector employee lived below the poverty line of 665,300 GHC. The percentages for the private sector employee, non-farm self-employed, and miscellaneous households were 8%, 21% and 20% respectively. On average, in Kenya, more than 50% of the population lived below the poverty line of 14,868 KES in 2001. The most affected were female-headed households in rural areas. In Tanzania, 38% of rural households, and 23% of urban households lived below the poverty line. The value of poverty line decreased due to a decrease in relative prices. The poverty estimates show that, in Ghana, 8% of the private sector employees lived in poverty in 1999. The incidence of poverty was higher among non-farm self-employed households. The estimated indexes are lower when compared to indexes from other countries in Sub-Saharan Africa.

The head count estimates for Kenya show that 54% and 53% of female-headed households in rural and urban areas, respectively, lived below poverty line in 2001. The corresponding values were 51% and 50% for male-headed households. Incidence of poverty was relatively low among male-headed households in urban areas. Incidence of poverty in Tanzania was higher in rural areas (38%) than in urban areas (23%). Lower incidence of poverty in both Kenya and Tanzania can be attributed to relatively higher per capita income among urban dwellers.

Another measure of poverty is the poverty gap index, defined as the difference between the level of income of a household group and the poverty line, and expressed as a proportion of the poverty line. Non-poor households have a poverty gap of zero. This measure is superior to the headcount because it indicates the depth of poverty. Poverty severity index is the mean of the squared poverty gap. As individuals in poorer households receive greater weight than less poor individuals, it provides a better measure than the other two measures of poverty. The poverty severity index is sensitive to the distribution of consumption levels among the poor, whereas the other indices are not. One poor person sacrificing income so that a poorer person's income is enhanced will alter neither the poverty headcount nor the poverty gap index. However, this action will decrease the poverty severity index. Greater measures of all the indexes imply poverty is worse, but overall, using the poverty headcount is intuitive. The other two indexes are more useful in making comparisons between different populations. Decisions relating to implementation of any poverty reduction program should target groups with the highest poverty severity index (Benson et al., 1998). For example, results from this study suggests that poverty alleviation programs should focus on the non-farm sector employee in Ghana, female-headed households in Kenya, and rural households in Tanzania.

In Table 5, the column on the percentage change in poverty gap shows the proportion of individuals that move out of the poverty gap. In Ghana, about 5% of the agricultural farmers moved beyond the new poverty line after aquaculture expansion. The changes in poverty gap indicate the most likely beneficiaries of the program. In Ghana, non-farm self-employed households benefit the most (most likely the middlemen). In Kenya, aquaculture programs are most likely to benefit urban households and especially male-headed households (most likely fish traders). In Tanzania, both rural and urban households will benefit from an aquaculture development program. From these results, it is apparent that the greatest impact of increased aquaculture production is through indirect and induced effects. This is important especially when planning for economic development and poverty alleviation. Sectors that indirectly create demand for goods from other sectors should be targeted first. Intersectoral linkages are important for job creation and economy wide expansion.

Table 5: Results of Poverty Analyses.

		Minimum income after simulation	Poverty line after simulation	Poverty head count	Poverty gap [a]		Severity		Change in poverty gap
					Before	After	Before	After	
Ghana (GHC)									
Agricultural farmers		9,198	556,038	0.173	0.171	0.163	0.168	0.164	-0.046
Public sector employee		16,570	555,451	0.193	0.188	0.177	0.184	0.178	-0.059
Private sector employee		14,400	555,464	0.080	0.078	0.074	0.077	0.074	-0.055
Non-farm self employed		28,638	557,867	0.210	0.201	0.185	0.192	0.185	-0.080
Miscellaneous households		16,486	562,380	0.200	0.195	0.184	0.190	0.185	-0.058
Kenya (KES)						0.000			
Rural Households	Female	1,495	14,478	0.540	0.486	0.422	0.437	0.426	-0.130
	Male	2,123	14,456	0.510	0.437	0.362	0.375	0.364	-0.172
Urban households	Female	2,267	14,580	0.530	0.449	0.368	0.381	0.370	-0.181
	Male	2,543	14,455	0.500	0.414	0.331	0.344	0.333	-0.201
Tanzania (TZS)						0.000			
Rural Households		6,173	86,298	0.380	0.354	0.319	0.330	0.321	-0.099
Urban households		6955.38	90435.00	0.23	0.21	0.19	0.20	0.19	-0.10

[a] Calculated based on Equation 1 were z is the poverty line and y minimum income of the household groups.

CONCLUSIONS

Policy implications

There is increased interest and policy support towards aquaculture development in Africa. Aquaculture development programs have the potential of creating new jobs, improving food security among poor households, removing variability in terms of household income flow, and increasing farm level efficiency and sustainability. This study used computable general equilibrium models for Ghana, Kenya, and Tanzania as case studies to estimate the effects on poverty alleviation from aquaculture expansion and productivity growth in intermediate inputs and primary factors used in aquaculture production in Sub-Saharan Africa. The general results suggest that aquaculture expansion will have positive effects in terms of per capita income in all households in Ghana and Kenya. In Tanzania, some rich households will experience income loss due to resource shift from the fisheries and manufacturing sectors to aquaculture. The poverty gap decreased in all households groups in all countries due to decreases in poverty lines associated with decreases in relative price and increases in the minimum income associated with income expansion. Sectoral-linkages, makes aquaculture development promising for sector-specific policy support aimed at aquaculture development to sustain poverty alleviation programs among poor households.

ACKNOWLEDGMENTS

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ASSESSMENT OF COASTAL AND MARINE AQUACULTURE DEVELOPMENT FOR LOW TROPHIC LEVEL SPECIES

Twelfth Work Plan, Economic Risk Assessment and Social Analysis 1 (12ERA1)
Abstract

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This report aims to provide the Aquaculture Collaborative Research Support Program (ACRSP) an overview of the literature-to-date regarding use of low trophic level species in nearshore aquaculture development around the world. Additionally, the study analyzes the current literature to assess and prioritize research needs as they relate to culture of low trophic level species in the nearshore. This project was initiated 1 January 2005 and will be completed 30 April 2006.

The first part of our activity will provide a broad summary of the ecological, economic, and sociopolitical concerns or issues repeatedly cited in the literature regarding the development of low trophic level nearshore aquaculture. The second part will detail methodologies used to search the literature and index the collected data in tabular form. The third part of this report will provide detailed analysis of three case studies, each of which involves the use of low trophic level nearshore aquaculture for three distinct purposes: 1) effluent treatment for high intensity production systems; 2) small-scale production of food and income; and 3) enhancement/replacement of wild capture fisheries. The report's conclusion will identify specific research needs and gaps in the literature and propose several strategies by which the ACRSP could address these research needs.

The literature relating to this topic is immense and extremely diverse, and the possibilities for low trophic level systems in the nearshore are innumerable and routinely site specific. Low trophic nearshore aquaculture occurs in a multitude of forms that include monoculture, polyculture, and integrated culture, and the number of species currently utilized in these projects is highly varied. We found research on nearshore low trophic level systems on six of seven continents and scattered throughout several island nations. Moreover, it is clear from the literature that on-the-ground development of new technologies and systems for low trophic level nearshore aquaculture has either preceded or is occurring simultaneously with academic research on these systems.

We draw several conclusions regarding the development of low trophic level aquaculture in the nearshore region. In general, despite the large body of literature, substantial research is needed. The fact that the dynamic nearshore region is so poorly understood necessarily makes aquaculture development there a complex endeavor. If done hurriedly and without understanding of site-specific nearshore processes, aquaculture could contribute to eutrophication and severe degradation of the region. Moreover, myriad ecological, economic, social, political, and cultural values of nearshore regions necessitate an interdisciplinary approach. We conclude that the development of low trophic level aquaculture in the nearshore should focus on extensive and/or semi-intensive systems to avoid ecological impacts. Thus, rigorous niche market development will be needed to support the variety of systems established. In addition to market development, the aquaculture industry needs to invest in well-researched marketing campaigns for nearshore projects in order to counter its predominantly negative image. Because we recommend that development of nearshore low trophic aquaculture be based upon a site-specific assessment of social, political, cultural, economic, and ecological factors, we avoid making highly specific recommendations regarding nearshore locations for aquaculture development. However, we will present case studies of successful nearshore low trophic level projects, provide numerous examples of locations in which they appear to be working successfully, and provide a decision-making tree to assist in determining whether a particular nearshore location has desirable qualities for low trophic level aquaculture development.

HYDRAULIC, WATER QUALITY, AND SOCIAL ASSESSMENT OF THE NZOIA RIVER BASIN

Twelfth Work Plan, Economic/Risk Assessment and Social Analysis 2 (12ERA2)
Abstract

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The primary goal of the watershed ecology research component will establish the ecological health and potential of aquatic and terrestrial ecosystems to have a potential negative impact on the river system. The health potential of the watershed will be inferred by integrating current and historical conditions at a sampling site of similar, unimpaired reference. This acts as a benchmark against which data from watershed health surveys will be compared to determine the existence of any impairment at the sampled sites. Impairments are defined as deviations from the normal expected natural site conditions. The magnitude of the divergence from the expected site conditions represents the severity of impairment. Developing a benchmark of watershed health potential will be an initial step in setting general watershed rehabilitation goals.

Protocols for monitoring biophysical characteristics of the landscape conditions at sampling sites will be developed throughout the watershed in order to capture the spatial distribution of landscape conditions as a function of biophysical and anthropogenic activities. These protocols will identify key indicator species, which must be identified for each physiographic region. Excellent in-country resources exist for ecological assessment
(e.g., http://www.iaia.org/Members/Publications/Guidelines_Principles and
http://www.kws.org/kwstidiploma.htm).

Both rural and urban land use within watersheds invariably affects biodiversity. This includes terrestrial and aquatic biota. Habitats are altered, leading to variation in biotic population structures. In streams the effects come in the form of variation in water quantity and quality. Land use generates both organic and inorganic pollutants that alter the physicochemical quality of the water. Such altered water characteristics in turn influence changes in biological communities. Pollutants entering a river system at identifiable points are often evaluated using physical and chemical measurement techniques. However, in certain situations, particularly in rural agricultural areas, pollutant sources are more diffuse and can make it difficult to take direct measurements. Fish and macroinvertebrate communities are good indicators of ecosystem quality, as the kinds and abundances of animals will vary according to a wide variety of physical habitat differences, such as habitat size, temperature, stream flow or water depth, and pollution. The present surveys will aim at describing: a) the community structure, and b) community processes and interaction for both fish and macroinvertebrates throughout the Nzoia River basin. The cause/impact relationships of land use and biological communities have been used fairly successfully in Europe and the United States to diagnose ecological health of watersheds. This has been done based on identifying a portfolio of impact indicator species.

Plans were made to begin the assessment of hydrological and ecological baselines. The decision was made to focus on two subwatersheds to be identified following a host country PI visit to several subwatersheds. Subwatersheds were selected based on: 1) particular conditions existing at the sites; 2) ease of access for sampling purposes; and, 3) the ease of collection of relevant social data for the PRA analyses. The Kapolet and Moiben subwatersheds were subsequently selected.

FARMERS TRAINING IN TANZANIA

Twelfth Work Plan, Economic/Risk Assessment and Social Analysis 3 (12ERA3)
Abstract

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The Tanzania Fisheries and Aquaculture Development Division depends on farmer training workshops as a major means of sustainable technology transfer in addition to extension services. Most on-farm research activities are conducted by the Sokoine University of Agriculture in collaboration with Kingorwila National Fish Center's Fisheries and Aquaculture Development Division. Both institutions are in the Morogoro Region. The proposed training will involve 25 fish farmers from different participating villages in the Morogoro Region. The training is important for developing model fish farmers who will participate in future research activities and extend the knowledge gained to other fish farmers in the region.

The training will be a five-day workshop conducted in collaboration with Mkindo Farmers Training Center. The major topics to be covered are pond construction, pond management, fish health, fish nutrition, economics of production, and marketing. Training instructors will come from the Sokoine University of Agriculture, Kingorwila National Fish Center, Moi University in Kenya, and the University of Arkansas at Pine Bluff, USA. The workshop is scheduled to take place in November 2005. The training activities will be based on training modules, and trainees include women and household members who manage fish ponds.

It is anticipated that farmers will acquire knowledge that will be used to improve farm productivity. The training will help to accelerate the adoption process of improved technical innovations through farmer-to-farmer knowledge transfer.

EX ANTE ASSESSMENT OF AQUACULTURE DEVELOPMENT: CHARTING THE STRENGTHS AND WEAKNESSES OF LOW TROPHIC SPECIES FOR OFFSHORE AQUACULTURE IN DEVELOPED AND DEVELOPING COUNTRIES

Twelfth Work Plan, Economic/Risk Assessment and Social Analysis 5 (12ERA5)
Abstract

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This report examines the ex ante development of low trophic marine organisms in exposed ocean conditions with an emphasis on the developing world. Overall, we found an overwhelming preference for high-value finfish culture regardless of location; high value product being deemed necessary to offset the large costs and risks associated with farming in exposed ocean sites. This focus has tended to obscure attention on the primary utilization of low trophic marine species in the development of exposed ocean culture systems. Drawing from a series of case studies, interviews and literature review, we first provide a series of sustainable developmental criteria that must be met; site selection, biological and economic factors related to culture systems, property rights, environmental standards and contributing to community development and avoiding user conflicts need much more consideration. We then examine ten low trophic candidate species in terms of their sustainable development potential. Our findings reveal that at present, sponge, blue mussel and perhaps pearl culture may warrant some further examination. For developing countries, offshore aquaculture of low trophic species must compete with near shore systems that hold marked advantages in terms of economic and social economies of scale. In exposed ocean environments, high investment costs, established technology, managerial expertise and achieving efficient economies of scale in both production and post-harvest phases will remain significant obstacles for future sustainable development efforts in developing countries.

INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED CLIMBING PERCH (*ANABAS TESTUDINEUS*) IN CAGES SUSPENDED IN CARP POLYCULTURE PONDS IN BANGLADESH

Twelfth Work Plan, Applied Technology and Extension Methodologies 1a (12ATE1a)
Abstract

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An on-farm trial is being conducted to adapt integrated cage-cum-pond systems to local farm conditions in Bangladesh, to determine appropriate stocking ratio of climbing perch (*Anabas testudineus*) in cages and carps in open water of ponds, to assess growth and production of fishes in both cages and open ponds, and to assess the economic and environmental benefits of this integrated system.

Eighteen farmers' ponds, ranging from 200 to 640 m^2 in surface area, were selected from three villages of Charbangalia, Pagalpara, and Ghoseber of the Haluaghat Upazila, Mymensingh district. Climbing perch and carps were stocked in cages and open water of ponds, respectively, to give caged to open-pond fish ratios of 1:1 and 2:1 as three treatments with four replicates each. On 23 August 2005, fingerlings of silver carp (*Hypophthalmichthys molitrix*), catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), Swrpunti (*Puntius sarana*), and common carp (*Cyprinus carpio*) were stocked at approximately one fish m^{-2} with a species ratio of 5:4:4:4:2:1 in open water of all ponds, while climbing perch fingerlings were stocked in one or two 1-m^3 cage suspended in each pond to give cage to open-pond fish ratios of 1:1 and 2:1. There were also four control ponds without a cage (0:1). Control ponds were fertilized fortnightly with cow dung. Commercial pelleted feed (35% crude protein) was given to caged fish twice daily at a rate of 10% body weight per day in the first month and reduced rates in the rest of the culture period. No feed or manure was added into open water of the treatment ponds. The on-farm trial will be terminated in January 2006 after five months of culture.

INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED AFRICAN CATFISH (*CLARIAS GARIEPINUS*) IN CAGES SUSPENDED IN CARP POLYCULTURE PONDS

Twelfth Work Plan, Applied Technology and Extension Methodologies 1b (12ATE1b)
Abstract

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An on-farm trial is being conducted to adapt integrated cage-cum-pond systems to local farm conditions in Nepal, to assess growth and production of fishes in both cages and open ponds, and to assess the economic and environmental benefits of this integrated system.

Eighteen farmers' ponds, ranging from 85 to 130 m^2 in surface area, were selected with six ponds from each of the three sites—namely, Taruwa village of Nawaiparasi district and Gothouli village and Kushahana village of Chitwan district. At each site there were three control ponds without a cage and three treatment ponds with the integrated cage-cum-pond treatment. African catfish (*Clarias gariepinus*) fingerlings of 10–15 g in size were stocked at 100 fish m^{-3} in a 1.5x1.5x1.1-m cage with water volume of 2 m^3 suspended in each treatment pond on 22–24 July 2005. Fingerlings of silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*) were stocked at 1 fish m^{-2} with a species ratio of 4:2:2:1:1 in open water of both control and treatment ponds on 5 August 2005. The control ponds were fertilized weekly using urea and diammonium phosphate (DAP) at 28 kg N and 7 kg P ha^{-1} $week^{-1}$. Commercial pelleted feed (30% crude protein) was given to caged fish twice daily at a rate of 5% and 3% body weight per day for small size (< 100 g) and large size (> 100 g) African catfish, which was sampled biweekly to adjust daily feed ration. No feed or fertilizer was added into open water of the treatment ponds. The on-farm trial will be terminated in December 2005 after five months of culture.

AQUACULTURE TRAINING FOR KENYAN EXTENSION WORKERS, FISH FARMERS, AND UNIVERSITY STUDENTS

Twelfth Work Plan, Applied Technology and Extension Methodologies 3 (12ATE3)
Abstract

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In an effort to stimulate an increase in the fingerling production of African catfish (*Clarias gariepinus*) the OSU/Kenya project (partners include Moi University Department of Fisheries, Kenya Fisheries Department, and OSU Department of Fisheries and Wildlife) is carrying out several training activities at Sagana Fish Farm, Moi University, and on private farms in Kenya. An increased supply of fingerlings will benefit both farmers wishing to produce catfish for the foodfish market and fishermen who use them as bait in the Lake Victoria long-line fishery. In addition, farmers who produce catfish fingerlings should realize increased earnings. The overall plan calls for the training of up to 34 extension workers and six advanced farmers in hatchery management techniques in two short courses conducted at government or university facilities; providing on-farm training in simple techniques for spawning, hatching, and rearing catfish juveniles for up to 12 farmers; providing short-term stipend support for four undergraduate students; and providing full support for two Moi University graduate (M.Sc.) students working on *Clarias* fingerling production problems in 2005 and 2006.

To date, two short courses for extension workers and advanced farmers have been held. The first was conducted at Sagana Fish Farm from 18–29 April 2005, with 14 extension agents and six farmers participating. The second was held at the Moi University Fish Farm from 14–17 August 2005. There were 30 participants in this second course; 19 were extension agents in the Kenya Fisheries Department, while five participants came from the Kenya Marine and Fisheries Research Institute and an additional six were hatchery managers supported by the Government of Uganda. Four undergraduate students in the Fisheries Department at Moi University have received support for short-term aquaculture-related projects during the first half of 2005, and full support is being provided to two M.Sc. students who began their studies in September 2004. The graduate students have completed most of their coursework and are currently engaged in their thesis research. Farmer training sessions will be conducted at one or two selected farms between November 2005 and March 2006.

TRAINING LOCAL FARMERS ON SAFE HANDLING OF STEROIDS AND MASCULINIZATION TECHNIQUES IN CENTRAL AMERICA

Twelfth Work Plan, Applied Technology and Extension Methodologies 4 (12ATE4)
Abstract

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Developing new techniques for the production of clean aquaculture effluents would be futile unless the information that is generated is transferred to people conducting aquacultural activities. This is especially difficult in Mexico and Central America because information is not readily accessible. Workshops conducted in Mexico under Aquaculture CRSP support have already impacted tilapia culture in Tabasco and Chiapas, and most farmers are growing sex-reversed tilapias. This activity was not conducted until only a few years ago. To complement research for the production of clean sex-inversion techniques, we believe that it is of vital importance to train farmers and extension agents and provide printed materials for the safe handling of steroids in aquacultural facilities. Workshops will be conducted in Central America with the goal of educating extension agents, technicians, students, and farmers on safe and effective sex inversion techniques. These personnel can then train additional growers. A manual in Spanish perpared at Universidad Juárez Autónoma de Tabasco will be used as the primary material at the workshops. The first workshop will be conducted in San Pedro Sula, Honduras, on 13 October 2005. In collaboration with Dan Meyer (Pan-American Agricultural School, Zamorano) we have invited farmers, students, and extension agents to participate in the Honduras workshop. Topics covered will be tilapia fry production, steroid characteristics, steroids in aquaculture, masculinization of fish, safe handling of steroids, use of charcoal filtration systems to eliminate methyltestosterone, and a description of successful operations in Mexico. We are currently establishing a network with farmers and researchers in Guatemala and Costa Rica to implement additional workshops.

ESTABLISHMENT OF THE CENTER FOR AQUACULTURE TECHNOLOGY TRANSFER

Twelfth Work Plan, Applied Technology and Extension Methodologies 5 (12ATE5)
Abstract

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Dissemination of technical information as part of extension outreach to producers is a critical aspect of sustainable aquaculture development. This project aims to build upon recent technology transfer efforts, including several established ACRSP projects in Mexico and an information network between US and Mexican universities of the Gulf Coast, by establishing a center for aquaculture technology transfer with a narrow focus that will service for all of Mexico. This center, which will be known as the Center for Aquaculture Technology Transfer (CATT), will be patterned after the US Sea Grant Program model. The CATT will be a virtual network of aquaculture research and extension universities and institutions in Mexico and the US that are united through a single mission, a central website, and a director. The overall mission of the CATT will be to enhance the implementation and adaptation of sustainable aquaculture technology and information from research, economic, and regulatory sources to aquaculture production stakeholders. The CATT will also serve as a uniting entity among members to guide research priorities and coordinate joint research funding wherever possible. The CATT will initially focus on one central theme: sustainable aquaculture development. As the program develops, its extension services can be expanded to include additional themes that are important to the country and region. Administration of the CATT, including its organizational structure, its director, and its priority interest areas will be determined by its membership. This project will support the creation and operation of the CATT by hosting an organizational meeting, providing Sea Grant coordination and extension guidance, providing salary support to the CATT director, and providing infrastructure support (e.g., internet/web service, telephone, and office materials).

DIVERSIFYING AND STRENGTHENING AQUACULTURE EXTENSION CAPACITY TO DEVELOP A REGIONAL EXTENSION SERVICE MODEL

Twelfth Work Plan, Applied Technology and Extension Methodologies 6 (12ATE6)
Final Report

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ABSTRACT

Building individual and institutional capacity for extension and community outreach is key to achieving aquaculture development and natural resources management goals. Capacity building for professionals working in extension or community development was the overall objective of this work. The first CRSP Cross-Sectoral and International Extension Exchange and Learning Workshop, held in June 2004, built on past and current extension efforts and extended them into new areas of learning. This included sharing of experiences from other sectors such as public health, agriculture, gender equity efforts and work with the physically challenged. As a part of the continuation of efforts to develop a strong, multi-institutional extension delivery service, a five day workshop was held in Mazatlan, Mexico from July 25–29, 2005 during which training in advanced extension methodologies, tools, and approaches were provided in a Training-of-Trainers mode.

Presentations and updates were given by 30 participants representing 20 institutions in five states in Pacific Mexico. Fifty to seventy-five participants attended each day. Participants included aquaculture extension agents and NGO representatives from Mexico and representatives from Ecuador and the US. An additional two days were spent planning and reviewing the progress of

the research associated with three case studies linked to the extension effort and for two additional ACRSP investigations.

Training in key topics related to the ACRSP investigations 12AHH1 (Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters) and 12AHH2 (Outreach and Planning for Implementation of Bivalve Growing Areas Classification and Related Sanitation Action Items) was provided by Dr. John Supan (Louisiana State University Sea Grant Program), Roberto Quintana (Research Associate, LSU Sea Grant Program), and Dr. Maria Haws (University of Hawaii Hilo and UH Sea Grant College Program).

The team visited Boca Camichin, Nayarit, a primary site for oyster culture and one of the ACRSP investigation sites, to begin planning for the investigations and to provide some experiential training in extension methods. An extension visit was also made to the oyster farm of Dr. Jorge Guevarra where culture of the native oyster is being revived.

Course materials from the workshop were compiled and distributed widely for the benefit of extension workers elsewhere. Further work required to build extension capacity was also discussed and an agenda was developed for future efforts.

INTRODUCTION

Extension is a recognized vehicle to raise awareness, modify behavior and transfer technology, but also represents one of the principal obstacles to developing and improving aquaculture in many parts of the world. This work was conducted in the context of several large scale conservation and bay management efforts that include elements of aquaculture development and management.

Long-term efforts have been made in Sinaloa, Mexico to establish a corps of extension agents to support the aquaculture sector and to work toward an inter-institutional extension delivery service capable of addressing issues impeding aquaculture development. Aquaculture on the Pacific Coast of Mexico is currently dominated by shrimp culture, but diversification is needed as shrimp operations become financially tenuous and to avoid potential impacts to sensitive wetlands habitats. Previous extension efforts by the workers involved in this project have therefore been directed at implementing best management practices to enable the shrimp culture industry to survive and become more sustainable. Diversifying aquaculture through increasing production of freshwater finfish and native species of bivalves have also been priority action items since the culture of native and low-input species falls under the umbrella coastal zone management efforts of the group. Efforts are also directed at making aquaculture and similar alternative livelihoods more inclusive of neglected stakeholder groups such as women, youth, and the physically disadvantaged.

This work focused on providing advanced training in extension methods and sharing experiences with other sectors and regions through a training-of-trainer event that provided ample opportunities for the participants to learn from each other and learn from the past experiences of group members. The training was conducted not only for capacity building purposes but also to support the three case studies and two new ACRSP investigations, and is linked to several efforts in conservation and aquaculture development.

The first extension training workshop was held in June, 2004 and included representatives from the UJAT ACRSP team and leading extension/researcher workers from other ACRSP countries including Nicaragua, Ecuador and Honduras. This exchange and the work on the three case studies has catalyzed a stronger multi-institutional extension effort in Sinaloa and Nayarit to support the growing trend towards mariculture development and diversification of aquaculture. Although shrimp farming continues to be one of the primary aquaculture activities on the coast of Pacific Mexico, increasingly both private sector and community-based efforts are looking at other species, both marine and freshwater, as forms of aquaculture, which are less risky, and more environmentally and socially sound. In particular, culture of bivalves is viewed as a traditional form of aquaculture and a local fishery that has potential to both improve current production and expand into new geographic areas and new communities.

The second extension exchange was both larger and more expansive in the range of topics covered, essentially becoming something akin to a regional aquaculture conference. Fifty to seventy-five participants representing the major institutions working in aquaculture on the Pacific Mexico coast attended each day of the meeting. Presentations related to the culture of marine finfish, bivalves, freshwater finfish (tilapia, catfish, bass, native cichlids), aquatic plants, and frogs. Training in advanced extension methods was also provided. An emphasis on bivalve culture and sanitation was also made in support of the two ACRSP investigations related to shellfish sanitation, policy, and regulation.

METHODS AND MATERIALS

This work was conducted as a training-of-trainer event and cross-sectoral exchange. Trainees and co-trainers were carefully chosen to include persons actively promoting aquaculture and those who could bring in diverse perspectives on extension. Seventy-five participants were drawn from a pool of candidates consisting of professionals who worked in some capacity related to aquaculture research or development including researchers, extension agents, educators, community development workers, and producers. Most of these individuals had taken leadership in extension activities, but none, with the exception of CESASIN personnel, were officially designated as extension agents within their institutions, this being a rather rare designation within Mexican institutions. Some participants were also chosen from community leaders in the communities under study in the related ACRSP case studies. Professionals with extension roles in other non-aquaculture sectors such as agriculture, public health, gender issues, and rehabilitation were also included to provide perspectives, tools and methods from other forms of community development. Finally, extension agents (Drs. John Supan and Maria Haws) from the US participated in order to share their experiences, particularly to highlight US models of cooperative extension such as the Land Grant and Sea Grant Programs. Training included five days of materials covering extension concepts, methods, models and tools, and technical topics for production aquaculture.

Two days of meeting were also held to plan and organize the two ACRSP investigations, 12AHH1 (Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters) and 12AHH2 (Outreach and Planning for Implementation of Bivalve Growing Areas Classification and Related Sanitation Action Items). Work was also done on the ACRSP Human Health and Aquaculture Case Studies: 11AHHR2 (Connectivity of Water Resource Status, Environmental Quality, Aquaculture, and Human Health); 11AHHR3 (Analysis of Critical Points in Aquaculture Production Affecting Participation and Level of Benefits to Women, Youth, and Disadvantaged Stakeholders); and 11DPPR1 (Food Safety and Handling: Increasing Local Consumption of Aquaculture Products and Improving Quality). The drafts of these case studies had been completed and the group was able to meet to review them and discuss what revisions and editorial work was needed to complete the work.

An extension visit was also made to several oyster farming communities located in Boca Camichin, Nayarit, where a native species of oyster (*Crassostrea corteziensis*) has been cultured for 20 years. This estuary area will be one of the two sites of 12AHH1 investigation, the other being Bahia Santa Maria in northern Sinaloa State. There is also potential in both sites to greatly improve production, sanitation, processing, and marketing of shellfish, which are topics of the ACRSP and other institutional efforts. Dr. Supan and Roberto Quintana also made an extension visit to the oyster farm of Dr. Jorge Guevarra, located north of the city of Mazatlan. His son, Jorge Guevarra, Jr. who serves as farm manager, subsequently visited Dr. Supan's oyster hatchery and research facility at Grand Isle, Louisiana for further training.

RESULTS

Two multi-sectoral planning meetings were held to prepare for the workshop and were also used as opportunities to work on the Human Health and Aquaculture case studies.

Training was provided to 75 professionals from various development sectors and other ACRSP countries or the SUCCESS projects, many of who continue to use the acquired skills in their extension efforts.

The preliminary findings of the three case studies were reviewed, input and comments were gathered from the group of experts, and the work plan was revised to cover the remainder of the work.

Training materials from the workshop were compiled on a CD, which was provided to all 75 participants and distributed to another 20 stakeholders. Materials have also been posted the PACRC/UHH website to increase accessibility.

The training materials are also being used for training in the five-year extension training effort that is taking place under sponsorship of the USAID/EGAT SUCCESS project. Specifically, materials have been used in Nicaragua, Ecuador and Tanzania.

Two extension visits were made to oyster farming areas. The visit to Boca Camichin also allowed the team to begin planning for the shellfish sanitation shoreline survey (Investigation 12AHH1).

Stronger institutional ties are being formed between the various institutions working together on ACRSP projects and related efforts. Specifically, UAS, UAN, CIAD, and CESASIN are working in a much more coordinated fashion to deliver extension and research services.

Ties with US universities and institutions such as Sea Grant are being strengthened.

Ties and coordination with the USAID/SUCCESS project sites are being developed.

One oyster farmer, Jorge Guevarra Jr. received further training at Dr. Supan's facility in Louisiana in oyster culture and hatchery methods.

CESASIN, the quasi-governmental agency responsible for aquaculture sanitation in Sinaloa and focuses largely on shrimp farming, has decided to expand its services (extension, diagnostic laboratory) to shellfish producers and to also convene a shellfish producers' steering committee.

DISCUSSION

The Pacific Mexico coastal line has great need for outreach and extension to support the communities' efforts to improve their conditions. The need for livelihoods to provide the basics of food, health, and education are rapidly growing due to accelerating trends related to migration to coastal areas, degradation of natural resources affecting the health and food security of stakeholders, lack of alternatives forcing stakeholders into unsustainable activities such as illegal fishing, drug smuggling and organized crime, and issues associated with globalization. Mexico in particular is affected by globalization and free trade initiatives due to its proximity to the US, which is its largest trading partner, and also an almost irresistible attraction to would-be migrants. At the same time, Mexico is uniquely positioned to take positive advantage of its status as a democratic, semi-industrialized nation and a potentially strong partner in global trade if the basic needs of rural and poor stakeholders can be met. Aquaculture is one of the leading alternatives for coastal areas and the need for developing a multi-institutional extension delivery system to support its growth is widely recognized.

As in many areas of the world, providing adequate extension assistance to stakeholders involved in aquaculture faces many challenges. Among the most common issues are lack of funding, lack of resources, large geographical coverage area, limited training in extension methods, and lack of government support for extension efforts.

The fundamental bases for many of the obstacles are institutional gaps, overlapping jurisdictions of institutions, and a lack of incentives encouraging professionals to engage in extension activities. Some of these obstacles occur at the level of an individual employee. Few positions exist where extension duties are explicitly required or supported. Employee evaluation processes often do not reward extension activities as much as research activities. Few institutional incentives exist to collaborate with colleagues within institutions and much less so with colleagues in other institutions. Other obstacles exist at the institutional level. Coordination and communication between institutions is often difficult and overlapping jurisdictions may actually lead to competitive situations. While certain government institutions are required by law to cooperate, large cumbersome bureaucracies often make this difficult. Institutional rewards for collaboration need to be improved.

Additionally, finding ways to connect scientists with stakeholders so that research results can benefit those involved in natural resources management, economic development and production is often difficult to achieve. Mexico has strong, vibrant research institutions, but often procedures, models and incentives do not lead to scientists taking active roles in working with stakeholders or cooperating with other institutions. The US model of cooperative extension or systems whereby an employee can hold dual research and extension roles is relatively unknown. Interestingly, the two ACRSP workshops were the first formal training many of the participants had received in extension, particularly for the participants who focus primarily on research. While it may be still too early for immediate improvements to be noted as a result of the capacity building, several participants have observed that they are now much more conscious of how their research can be linked to and positively affect community development. Progress has also been made since the first extension workshop in June 2004 in developing multi-institutional cooperative efforts in extension.

Despite the wide-ranging impediments, individuals and institutions in Pacific Mexico have come together on many occasions to work jointly on aquaculture, community development, and coastal management efforts in coastal communities, although this is often the result of individual initiatives or friendly relationships. One thrust of the workshop was to learn from these experiences and use the findings to develop more formal, institutionalized means of providing regular and responsive extension assistance to communities. This is linked to the research and field studies that were conducted by a multi-institutional working group that represents group efforts to address complex and multi-sectoral issues. These working experiences and development of initial agreements for cooperative work will be a first step towards improving extension capacity.

CONCLUSIONS

Capacity building in extension methods and linking the capacity building with efforts in the field has been beneficial in establishing the basis of working partnerships between institutions and individuals in Sinaloa for a multitude of community development efforts, including aquaculture. Further work is needed to continue with the skill building for extension and research professionals. Support in the form of funding and institutional incentives for conducting extension would go a long ways towards enhancing the ability of interested professionals to work effectively in aquaculture extension.

ANTICIPATED BENEFITS

Quantitative and qualitative benefits include:

- 75 professionals trained in advanced extension methods and aquaculture skills.
- Leaders and members from 5 communities participated in the training.
- 22 institutions participated in the workshops.

- A learning exchange occurred between aquaculture professionals and those working in other sectors.
- A learning exchange occurred with representatives of one other ACRSP countries (Ecuador).
- Training materials from the workshop have subsequently been used in three other ACRSP/SUCCESS sites (Nicaragua, Ecuador, and Tanzania).
- Of particular note is that 8 members of CESASIN, the primary aquaculture extension institution in the region, received further training.
- CESASIN has decided to expand its extension coverage to the shellfish sector.
- Professional in other sectors were made aware of the benefits of aquaculture for rural communities and the benefits to health.
- Issues related to human health and aquaculture were identified and characterized; this information was incorporated into the associated case studies.
- A gender balance was achieved with 45% of the participants being women.
- Connections between researchers and extension workers were strengthened or established.
- Extension training materials in Spanish were produced, distributed and made widely available.
- Results and skills stemming from this workshop greatly enhanced the Human Health case studies and two ACRSP investigations.
- Four students from UAS participated in this work directly and two students from UHH contributed to planning and preparation.

ACKNOWLEDGMENTS

A large number of institutions and individuals generously provided time, resources and personnel to support this effort. Funding was generously provided by: ACRSP; the David and Lucille Packard Foundation via a grant to the Coastal Resources Center/University of Rhode Island; the Office of the Chancellor, Autonomous University of Sinaloa; University of Hawaii-Hilo; and USAID/Mexico. Indirect support also came via connections with the USAID/SUCCESS project. Special thanks are given to the individuals within these institutions who supported these efforts: Hillary Egna (ACRSP); Pam Rubinoff and James Tobey (CRC/URI); Rose Tseng and Christopher Lu, UHH; Kevin Hopkins (PACRC/URI); Gómer Monárrez González, Ambrocio Mojardin and Eladio Gaxiola (UAS); and Sergio Knaebel (David and Lucille Packard Foundation).

Other support and resources were provided by a large number of host country institutions and their directors. UAS and its faculty oversaw the planning meetings and general logistics for the workshop (Eladio Gaxiola, Guillermo Rodriguez, Nicolas Castañeda). CESASIN (Luis Miguel Aguiar, Director, and Julio Cabanillas) supported planning and execution of the workshop, production of the workshop materials and minutes and provided general coordination. CREDES (Ana Luisa Toscana, Director) provide the workshop venue, dormitory space and food services for the participants. Conservation International (Armando Villalba) also provided support to the workshop logistics and planning. Additional support was also kindly provided by Irma Lorena Camacho Lòpez and Ruth Maria Garduño Gil who volunteered their time to provide oversight of all logistics and arrangements while the workshop was being conducted. The coordination efforts of the personnel from the Universidad Autonoma de Nayarit are also recognized. Dr. John Supan and Roberto Quintana made outstanding efforts for the training, extension visits and organization of future research.

The team also wishes to thank the following officials and individuals who participated in the opening ceremonies for the workshop by offering remarks or who participated in the round table for discussion of extension issues: Gómer Monárrez González (Rector, UAS), Sergio Escutia (President, CESASIN), Ramón Corral (National Fisheries Commission), Enrique Sánchez Cruz (Head, SAGARPA/Sinaloa), Samuel Sánchez Cabrera (Subsecretariat of Fisheries/Government of Sinaloa State), Ricardo Ramírez (President, Municipality of Mazatlan), Lorenzo Gómez Leal (Head,

PROFEPA/Sinaloa), Ana Luisa Toscazo (Director, CREDES), Cristina Chávez (Director del CIAD-Mazatlan), Ricardo Romero (consultant, industry representative), Ricardo Urias (Fisheries/SAGARPA), Isidro Osuna Lopez (UAS), and Carmen Torres (SEMARNAT).

Specials thanks are due to the numerous participants of the workshop who also served as co-trainers, thereby greatly improving the quality and outcome of the event.

The following individuals contributed materials for the workshop or allowed their training materials to be adapted for use: Gary Jensen (USDA/CSREES), John Jacobs (Texas Sea Grant Program), Brian Crawford (CRC/URI), John Supan (LSU Sea Grant Program), and Lisa King (PACRC/UHH).

Last but certainly not least, students from Mexico, Nicaragua, and the US provided key support to this effort: Luis Alberto Zumaya Tirado and Cinthya Guadalupe Lares Ureta (UAS), Abelardo Rojas Umaña and Candace Martin (UHH).

Figure 1. Workshop participants.

EVALUATION AND IMPROVEMENT OF TILAPIA FINGERLING PRODUCTION AND AVAILABILITY IN HONDURAS

Twelfth Work Plan, Seedstock Development and Availability 1 (12SDA1)
Abstract

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ABSTRACT

The lack of an adequate supply of all-male tilapia fingerlings has been identified by fish farmers as a principal constraint to small- and medium-scale fish culture development in Honduras. A survey of tilapia fingerling producers was conducted to evaluate tilapia fingerling production and examine the factors that influence the way farmers produce and distribute fingerlings. Sixteen farmers were identified and interviewed during the period from September 2003 to July 2004. Seed production is concentrated in the valley areas of Olancho, Comayagua, and Cortez, Honduras. Fingerling sex reversal with hormone-treated feed was practiced by 14 of the 16 farmers. Seven fingerling farms are family-owned, four are private companies, one is a cooperative, one is operated by a nonprofit organization, another run by a university, and two are government stations. From each of the farms, and in the manner that would be used by a typical producer, a minimum of 1,000 fingerlings were purchased and transported to the aquaculture station at Zamorano for evaluation (count, uniformity of size, and uniformity of color). A subsample of 250 fingerlings purchased from each farm was reared to a size when sex identification was possible. The sex of each adult fish was determined by visual examination of the genital papilla to ascertain the percent of males in each subsample. In aggregate, the sample produces approximately 15.3 million fingerlings per year.

Most (75%) of the fingerling producers interviewed also raise tilapia, produce other aquaculture species, and have other farm enterprises. Fingerling farmers have at least 4–6 years of formal education and fingerling production experience with an average of 6.7 years and a range of 0–25. This study considered three indicators of fingerling quality (uniformity of color, size, and male gender). The results show that there is higher variability for color and gender than for size among the fingerling batches evaluated. This variability suggests that the quality of fingerling delivered to tilapia farmers is not consistent. Most of the fingerling batches evaluated fall under the 90% level of uniformity of size, color, and gender. Only two independent variables had a significant relationship with fingerling quality. Farmer experience growing tilapia is positively related to fingerling quality production, but production training in itself was not related to fingerling quality, as producing seed is a specialized and skilled activity. High variability in sex reversal occurs in part because most farmers do not use standard methods of grading their fry and fingerlings by size, thus introducing inconsistency in hormone dosage and length of treatment. This is an area where training can accomplish improvement in the outcomes of the sex reversal practices as well the size uniformity of fingerling sold. Feeding methods could be one source of low quality. Producers often do not count fry in the sex reversal process, thus the feed they provide is often not well gauged to the number of fish. Some reported that when the demand is high, they sometimes sell fingerlings before the

recommended treatment period (28–30 days) is completed. Even though most farmers used the recommended protocol for the preparation of the hormone-treated feed (60 mg MT kg^{-1} of feed), some economize by lowering the dosage or using cheaper alcohol of a different type. Some use outdated hormone (more than four years old). One approach that has proven effective for some fingerling producers is to purchase prepared hormone feed from other farmers or institutions with more experience and access to the hormone source. Improving the level of practice among fingerling producers is a key step to improving quality and productivity in the industry.

STUDIES ON STRATEGIES FOR INCREASING THE GROWTH AND SURVIVAL OF AFRICAN CATFISH (*CLARIAS GARIEPINUS*) JUVENILES REARED FOR STOCKING OR FOR USE AS BAIT

Twelfth Work Plan, Seedstock Development and Availability 2 (12SDA2)
Abstract

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This investigation was initiated to look into possible techniques for increasing the survival of fry of the African catfish (*Clarias gariepinus*) reared to fingerling size for stocking in grow-out ponds or for use as bait in the Lake Victoria long-line fishery.

Possible management strategies identified in the project proposal for improving fry survival included varying the duration of the fry rearing phase; offering live, freeze-dried, and/or formulated feeds to hatchery-reared larvae in different sequences (as opposed to offering a single feed throughout the rearing period); and varying the stocking densities of catfish fry to be reared in the hatchery or in ponds.

Two Moi University M.Sc. students have undertaken thesis research focused on two aspects of the fingerling survival problem. One student, Victoria C. Boit, is conducting research on the "Effect of Sequential Feeding and Light Regime on Growth of the African Catfish (*C. gariepinus*) Fry." The other student, Stephen N. Njau, is working on the "Effect of Varying Hatchery Rearing Duration and Stocking Density on Growth and Survival Rates of African Catfish (*C. gariepinus*) Fry." The field and laboratory phases of these research projects will be completed by November 2005, and the students will have their theses ready for examination by their graduate committees by 30 June 2006. The work of these students is being supervised by Charles C. Ngugi (Moi University) and James R. Bowman (Oregon State University).

CONTINUATION OF A SELECTIVE BREEDING PROGRAM FOR NILE TILAPIA TO PROVIDE QUALITY BROODSTOCK FOR CENTRAL AMERICA

Twelfth Work Plan, Seedstock Development and Availability 3 (12SDA3)
Abstract

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The selective breeding program supported by the Aquaculture CRSP from 2001 to 2003 was initiated using 220 females and 110 males obtained from a batch of fish purchased from Egypt by the state government (Tabasco line). A second line is currently being selected from wild animals. We have identified a stock of wild Nile tilapia in the Usumacinta River that shows several advantageous phenotypic traits, such as a small head, small tail, large body, and uniform color (Wild Tabasco line). For the first year of work, we were able to combine the efforts of the Aquaculture CRSP project and a project supported by the National Council for Science and Technology (CONACyT-Mexico). This action allowed us to work at the Mariano Matamoros Hatchery using 200; 1,000; and 2,000 m^2 ponds and to use fish first selected by Mario Fernández in 2000. Adult fish were stocked in 200 m^2 ponds. From the fry obtained, three selections were made: one at 60 days; a second at 120 days (at this point the fish were separated by sex); and a third at 11 months. We have initiated the selection of organisms from the third generation (F3) of the Tabasco line, the wild line and the control fish (Teapa line). Two-thousand eight-hundred fish were stocked in 200 m^2 ponds using a density of 14 fish m^{-2}. Survival was similar in fish from the Tabasco and the Teapa line; however, fish from the control group had lower survival than the rest (80.5, 70.7, and 61.0%, respectively). Results measured in terms of weight, length, and biomass were very similar between the Tabasco and the wild line; the control was significantly lower than the other lines (12.8, 12.7, and 8.5 g, respectively). Eight-hundred fish were selected from the first batch and stocked in ponds at a density of 4 fish m^{-2}. After 90 days of growth, fish from the Tabasco line grew faster than the fish from the wild and the control groups (40.1, 32.9, and 31.1 g, respectively). A third selection was conducted in July. Two-hundred females and 66 males were selected as broodstock. Reproductive performance of the three lines is currently being evaluated. A final report will be submitted in June 2006.

DEVELOPMENT OF AQUACULTURE TECHNIQUES FOR THE INDIGENOUS SPECIES OF SOUTHERN MEXICO, CENTROPOMUS UNDECIMALIS: SEX DETERMINATION AND DIFFERENTIATION AND EFFECTS OF TEMPERATURE

Twelfth Work Plan, Seedstock Development and Availability 4 (12SDA4)
Abstract

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Species of "robalo," or snook, constitute one of the most important commercial fisheries along Mexico's coast in the Gulf of Mexico. The common snook has perhaps received the most attention and fishing pressure on the southwestern side of the Gulf, but spawning grounds for common snook have been reported as far north as the lower Laguna Madre and its associated estuaries in Texas. In Mexico, there is a trend for diminishing catch volumes for common snook, a situation that has led to concerns for the regional snook fisheries and calls for improved management practices. In Texas, there have been no reported commercial snook landings since 1961. The development of an aquaculture industry for common snook in Mexico would therefore benefit the Mexico-Texas populations by providing relief from the fishing pressure on wild stocks.

Female common snook are larger than males of the same age class, especially in younger fish. Thus, female snook may have an intrinsically faster growth rate than males. The present study focuses on an evaluation of rearing techniques to skew sex ratios toward females and lead to enhanced growth rates for farmed common snook. In order to accomplish this objective, it is first necessary to establish the pattern and timing of gonadal sex differentiation. Although it has been reported that common snook are protandric—they first develop as males before changing sex into females—basic information about gonadal sex differentiation is not available for this species. This information is needed to determine the time at which steroid treatment can be applied to feminize snook fry and bypass the male phase.

In Mexico, 17 field trips resulted in the collection of 266 individuals. Otoliths from 228 fish were extracted, of which 191 have been processed. Preliminary histological analyses at Texas Tech University indicated that, contrary to expectations, the gonads of some of the young fish collected in Mexico are initially developing directly as females. These observations could have important implications for the present study, but the results need verification by examination of additional samples. Histological analyses are expected to be completed by the end of this year. In addition, a system for fry rearing has been built and we are expecting to complete the spawning and the fry treatment phase by May 2006.

In the US, 32 miles of river were sampled from the mouth of the Rio Grande upstream along the US-Mexico border during January–March 2005. Cast nets, seines, and trawls were used to collect common snook. A total of 32 common snook were collected. Four additional snook were collected

using an electroshock boat in August 2005. Gonads and otoliths were extracted and will be processed for analysis by the end of this year. A second field season is planned for January–March 2006. One objective of the US study is to determine the early reproductive development of common snook in Texas. This objective is in support of the Mexico study and will provide information to help generalize the reproductive biology of the Mexico-Texas snook population. An additional objective is to characterize the natural habitat of common snook at its northernmost range. The US study is being supplemented by funds from the US Geological Survey, Texas Tech University, and Texas Parks and Wildlife.

EFFECTS OF NATIVE PERUVIAN FEEDSTUFFS ON GROWTH AND HEALTH OF *COLOSSOMA* AND *PIARACTUS*

Twelfth Work Plan, Fish Nutrition and Feed Technnology 1 (12FNF1)
Abstract

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Personnel at the University of Arkansas at Pine Bluff (UAPB) performed health assays on Colossoma macropomum used in a digestibility trial at Southern Illinois University at Carbondale. Blood was collected and hematocrit (Hk) and hemoglobin (Hb) were analyzed (Hb cyanide method, Houston, 1990). Mean corpuscular hemoglobin content (MCHC) was calculated based on the formula: MCHC = Hb concentration/Hk. The fish plasma was used for the analysis of alternative complement activity, a measure of the non-specific immune response.

Hemoglobin was not affected by diet, while hematocrit and MCHC were lower in the fish fed the plantain diet than those fed the control diet, but no explanation is obvious. Fish fed the yucca diet had higher complement activity than fish fed the control diet, indicating an immunostimulatory effect of the yucca.

A feeding trial is currently being conducted at UAPB with juvenile Colossoma macropomum to determine the effects of diets with cooked or uncooked plantain, pijuayo, and yucca on growth, survival, feed efficiency, and health parameters of gamitana. Six-week data showed no growth or survival differences among treatments. The trial will continue for four more weeks, then the same health parameters measured in the previous trial will be measured.

NUTRITION AND NUTRIENT UTILIZATION IN NATIVE PERUVIAN FISHES

Twelfth Work Plan, Fish Nutrition and Feed Technology 2 (12FNF2)
Abstract

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Native species aquaculture has been expanding in the Amazon region in recent years. *Colossoma macropomum* (Characiformes: Characidae) is the second-largest scaled, freshwater fish in South America. *C. macropomum* (black-finned pacu) is native to the Amazon Basin and possesses many characteristics suitable for aquaculture. Black-finned pacu is in high demand and attains a high price at the marketplace. However, no formulated diets are available specifically for *C. macropomum* culture. Consequently, a wide range of ingredients for locally manufactured formulated diets are used in the countries where this fish is cultured. These diets have variable crude protein (CP) which ranges from 18 to 43% CP, and the supplied ration ranges from one to five percent of the fish wet body weight. Commonly wheat, corn, and rice are some of the main energy sources in these formulated diets. As wheat is not traditionally cultured in the Amazonian region; it has to be imported from distant regions, thus limiting its use for direct human consumption. A growth experiment was conducted to determine the effect of substituting three alternative ingredients for wheat middlings on growth performance and conversion efficiency in Amazonian black-finned pacu (86.9 ± 6.4 g). Fish were fed a control and three practical diets for a 24 wk period and their growth rates and conversion efficiency ratios were determined and compared. Fish were fed at three percent of their wet body biomass divided in two daily rations of one of the four diets: 1) control diet (31.8% CP):; 2) cassava diet (27% CP); 3) plantain diet (27.5% CP); and 4) palm peach diet (28.1%). Fish weight and length were measured every two weeks. At the end of 24 weeks, the final mean weights of black pacu in the control, cassava, plantain, and palm peach diets were 538.8, 559.0, 552.7, and 527.4 g, respectively, and these values were not significantly different from each other ($P < 0.05$). Final mean weight gain of black pacu in the control, cassava, plantain, and palm peach diets were 458.2, 476.2, 465.8, and 437.8 g, respectively, and values were also not significantly different ($P > 0.05$). Diets tested did not significantly influence specific growth rate ($P > 0.05$) or feed conversion ratio ($P > 0.05$), however, they did influence protein efficiency ratio ($P < 0.05$). Based on these findings, it was concluded that all of the tested ingredients, cassava, peach palm or plantain meal can replace wheat middling in formulated diets for *C. macropomum* without adversely affecting fish growth performance.

A second experiment was conducted to determine digestibility of the three alternative ingredients tested in the previous experiment with *C. macropomum* in 110 L tanks in a flow-through system at Southern Illinois University at Carbondale. Digestible energy, protein, lipid, and dry matter digestibility coefficients were determined for each feedstuff. The reference diet was similar in composition to those used currently for Characid fishes at Instituto de Investigaciones de la Amazonía Peruana (Peru). Digestibility coefficients were determined by using an indirect method, involving chromic oxide (Cr_2O_3) as a non-digestible marker. The digestibility of crude protein (86.5%), crude fat (90.6%), and energy (62.6%) of pijuayo in *C. macropomum* was far superior to that

of yucca and plantain. The digestibility of plantain and yucca by *C. macropomum* were very similar to each other for crude protein (53.9 vs. 48.3%), crude fat (50.9 vs. 57.5%), and energy (23.7 vs. 14.4%). Pijuayo appears to be an excellent ingredient to be employed in formulated diets for *C. macropomum*. Additionally, the abundance of pijuayo in the Amazon Basin makes this fruit economically viable to the small-scale farmers to reduce feed manufacturing cost.

USE OF PHYTOCHEMICALS AS A NEW METHOD TO SEX-REVERSE NILE TILAPIA AND TROPICAL GARFISH

Twelfth Work Plan, Fish Nutrition and Feed Technology 3 (12FNF3)
Abstract

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Longnose gar (*Lepisosteus osseus*) broodstock were obtained with the cooperation of the US Fisheries and Wildlife Service and the Aquatic Ecology Laboratory at The Ohio State University on the Sandusky River, Ohio, in late March 2005. Fish were acclimated in 400 L circular tanks for several weeks. In June 2005, presumptive females (n = 2) and males were identified and separated into groups of one female and 3 males. The remaining males were kept separately. Substrates (plastic plants) were provided in tanks with mixed-sex fish. To induce final maturation, fish were injected with a hormone priming dose and then, eight hours later, with a resolving dose as suggested in the instructions of OVAPRIM® (Syndel International Inc., Vancouver, Canada). Eggs were released from only one female (23 June 2005), and sperm was observed in only two out of 15 males. The ovulating female was then stripped of eggs several times within the next 24 hours (approximately 400 eggs were released). A male garfish was sacrificed, and sperm preparation was obtained from macerated testes to assure insemination. Viable eggs were obtained mostly during the first stripping, and fertilization was negligible in eggs from the following ovulations. In total, 106 larvae hatched after incubation for eight days at 18° C.

A feeding trial was designed with obtained larvae (initial weight 37.3 mg, length 23.5 mm), where fish were distributed in nine 35 L glass aquaria at the density of 11 fish tank^{-1} (14 July 2005). Control groups were fed with live *Artemia nauplii*. In two other treatments we attempted to provide a formulated, commercial diet (AgloNorse, Ewos, Norway; 59% protein 16% lipids) for two days. As no feeding was observed, all groups were offered live *Artemia nauplii* for the following four days. The second attempt of weaning live food groups onto a commercial diet (AgloNorse) (3 tanks) or the same feed (Aglonorse) with 60 mg kg^{-1} 17α-methyltestosterone (MT) (3 replicates per treatment) was carried out when fish were 37.4 mm total length. Fish were fed ad libitum for 26 days. Several fish were fixed for histological analysis at the time of initiation of feeding with exogenous food and at the completion of MT-treatment. These fish are prepared for histological examination of gonad development and differentiation. We conclude that garfish larvae/juveniles can be effectively adapted to consume dry artificial diets at early life stages, and the hormonal treatment could be included within the first week of exogenous feeding. Upcoming activities will be focused on description of the morphological development of the gonad and differentiation processes in the longnose gar by histological analyses.

The second objective of the project, work on sex differentiation in Nile tilapia, concentrated on identification of parental genotypes associated with sex genes (XX males). The preliminary results of group spawning of fish obtained from the Philippines (40 females and 5 males) (November 2003, Phil-FishGen, Nueva Ecija) provided evidence of a high prevalence of female phenotypic gonads (80%). We were able to produce at present 8 groups of progenies from tagged fish. These fish will be evaluated for sex ratio and identified parental stock used for mass larvae production. We expect to be able to produce 600 to 1,500 larvae within six to eight weeks to start feeding trials as described in Study 1 in the Twelfth Work Plan.

CROSS-SECTORAL AND INTERNATIONAL EXTENSION EXCHANGE AND LEARNING

Eleventh Work Plan, Aquaculture and Human Health Impacts 1 (11AHHR1)
Final Report

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ABSTRACT

Building individual and institutional capacity for extension and community outreach is key to achieving aquaculture development and natural resources management goals. Capacity building for professionals working in extension or community development was the overall objective of this work. The ACRSP Cross-Sectoral and International Extension Exchange and Learning Workshop built on past and current extension efforts and extended them into new areas of learning. This included sharing of experiences from other sectors such as public health, agriculture, gender equity efforts and work with the physically challenged. A three-day workshop was held in Mazatlan, Mexico from June 14–16 during which training in extension methodologies, tools, and approaches were provided in a training-of-trainers framework. Participants included aquaculture extension agents and NGO representatives from Mexico, representatives from other ACRSP initiatives in Mexico, Peru, and Honduras, and project personnel from other innovative aquaculture extension efforts (e.g., UCA/Nicaragua and Ecocostas/Ecuador). Participants from non-aquaculture sectors such as agriculture, public health, community development and rehabilitation of the handicapped shared their methods and lessons learned to help strengthen aquaculture extension methods within a community development context. An additional two days were spent planning and reviewing the progress of the research associated with three case studies linked to the extension effort. Course materials from the workshop were compiled and distributed widely for the benefit of extension

workers elsewhere. Further work required to build extension capacity was also discussed and an agenda was developed for future efforts.

INTRODUCTION

Extension is a recognized method that raises awareness, modifies behavior and transfers technology, but also represents one of the principal obstacles to developing and improving aquaculture in many parts of the world. This work was conducted in the context of several large-scale conservation and bay management efforts that include elements of aquaculture development and management.

Long-term efforts have been made in Sinaloa, Mexico to establish a corps of extension agents to support the aquaculture sector and to work toward an inter-institutional extension delivery service capable of addressing issues impeding aquaculture development. Aquaculture on the Pacific Coast of Mexico is currently dominated by shrimp culture, but diversification is needed as shrimp operations become financially tenuous and to avoid potential impacts, particularly those associated with sensitive wetlands habitats. Previous extension efforts by the workers involved in this project have been directed toward implementing best management practices to enable the shrimp culture industry to survive and become more sustainable. Diversifying aquaculture through increasing production of freshwater finfish and native species of bivalves have also been priority action items since culture of native and low-input species fits well with the umbrella coastal zone management efforts of the group. Efforts are also being made to make aquaculture and similar alternative livelihoods more inclusive of neglected stakeholder groups such as women, youth, and the physically disadvantaged.

This work focused on providing initial training in extension methods and sharing experiences with other sectors, as well as ACRSP project personnel from other regions through a training-of-trainer (T-O-T) event that provided ample opportunities for the participants to learn from each other and past experiences. The training was conducted not only for capacity building purposes but also to support the three case studies and is linked to several efforts in conservation and aquaculture development.

METHODS AND MATERIALS

This work was conducted as a T-O-T event and a cross-sectoral exchange. Trainees and co-trainers were carefully chosen to include persons actively promoting aquaculture and those who could bring diverse perspectives on extension. Seventy-five participants were drawn from a pool of candidates consisting of professionals who worked in some capacity related to aquaculture research or development including researchers, extension agents, educators, community development workers, and producers. Most of these individuals had taken leadership in extension activities, but none were officially designated as extension agents within their institutions, this being a rather rare designation within Mexican institutions. Some participants were also chosen from community leaders in the communities under study in the related ACRSP case studies (11AHHR2, 11AHHR3, 11DPPR1). Professionals with extension roles in other non-aquaculture sectors such as agriculture, public health, gender issues, and rehabilitation were also included to provide perspectives, tools and methods from other forms of community development. Participants from other Latin American ACRSP efforts and countries were also invited including representatives from Honduras (El Zamorano/INFOP), Nicaragua (UCA), UJAT/Tabasco, Mexico and Ecuador (Ecocostas). Finally, extension agents from the US participated in order to share their experiences, particularly to highlight US models of cooperative extension such as the Land Grant and Sea Grant Programs.

Training included three days of materials covering extension concepts, methods, models and tools. This was accompanied by presentations by invited speakers from non-aquaculture sectors. The materials presented at the workshop are available in DC form in Spanish, or on the PACRC/UHH website (www.uhh.hawaii.edu/~pacrc). An additional three days of sessions were then held for the participants in the Human Health and Aquaculture case studies to present their preliminary findings and plan for completion of the work. The external specialists also had an opportunity to review the work and provide input.

RESULTS

Three mult-sectoral planning meetings were held to prepare for the workshop and were also used as opportunities to work on the Human Health and Aquaculture case studies.

Training was provided to 75 professionals from various development sectors and other LAC ACRSP projects, many of whom have since continued to use the acquired skills in their extension efforts.

The preliminary findings of the three case studies were reviewed, input and comments were gathered from the group of experts, and the work plan was revised to cover the remainder of the work.

Training materials from the workshop were compiled on a CD, which was provided to all 75 participants and distributed to another 20 stakeholders. The materials have also been posted the PACRC/UHH website to increase accessibility. These materials are also forming the basis for a five-year extension training effort that is taking place under sponsorship of the USAID/EGAT SUCCESS project.

The group also outlined a framework of guiding principals that could lead to formalized cooperation between institutions to improve extension. This was drafted as the "Declaration of Mazatlan".

DISCUSSION

The Pacific Mexico coastline has great need for outreach and extension to support the communities' efforts to improve their conditions. The need for livelihoods to provide the basics of food, health, and education is rapidly growing due to accelerating trends related to migration to coastal areas, degradation of natural resources affecting the health and food security of stakeholders, lack of alternatives forcing stakeholders into unsustainable activities such as illegal fishing, drug smuggling and organized crime, and issues associated with globalization. Mexico in particular is affected by globalization and free trade initiatives due to its proximity to the US, which represents its largest trading partner, and an almost irresistible attraction to would-be migrants. At the same time, Mexico is uniquely positioned to take advantage of its status as a democracy and semi-industrialized nation, and become a strong partner in global trade if the basic needs of rural and poor stakeholders can be met. Aquaculture is one of the leading alternatives for coastal areas and the need for developing a multi-institutional extension delivery system to support its growth is widely recognized.

As in many areas of the world, providing adequate extension assistance to stakeholders involved in aquaculture faces many challenges. Among the most common issues are lack of funding, lack of resources, large geographical coverage area, limited training in extension methods, and lack of government support.

The fundamental bases for many of the obstacles are institutional gaps, overlapping jurisdictions of institutions, and a lack of incentives encouraging professionals to engage in extension activities. Some of these obstacles occur at the level of an individual employee. Few positions exist where extension duties are explicitly required or supported. Employee evaluation processes often do not reward extension activities as much as research activities. Few institutional incentives exist to collaborate with colleagues within institutions and much less so with colleagues in other institutions. Other obstacles exist at the institutional level. Coordination and communication between institutions is often difficult and overlapping jurisdictions may actually lead to competitive situations. While certain government institutions are required by law to cooperate, large cumbersome bureaucracies often make this difficult. Institutional rewards for collaboration need to be improved. Additionally, finding ways to connect scientists with stakeholders so that research results can benefit those involved in natural resources management, economic development, and production is often difficult. Mexico has strong, vibrant research institutions, but often procedures, models, and incentives do not lead to scientists taking active roles in working with stakeholders or cooperating with other institutions. The US model of cooperative extension or systems whereby an employee can hold dual research and extension roles is relatively unknown. Interestingly, this workshop was the first formal training many of the participants had received in extension, particularly for the participants who focus primarily on research. While it may be still too early for immediate improvements to be noted as a result of the capacity building, several participants have observed that they are now much more conscious of how their research can be linked to and positively affect community development. Also, because research efforts are often conducted in relative isolation, learning about the on-going research initiatives of the various participants was viewed as very helpful and several new partnerships have been forged as a result. One example is the work of Dr. Silvya Paz who has identified and characterized the existence of gnathosome parasites in freshwater bodies and fishes, which present a serious health threat to anyone producing or consuming freshwater fish. This work was largely unknown until Dr. Paz presented her findings to the group, which includes the major aquaculture extension agents in the region.

Despite the wide-ranging impediments, individuals and institutions in Pacific Mexico have come together on many occasions to work jointly on aquaculture, community development, and coastal management efforts in coastal communities, although this is often the result of individual initiatives or friendly relationships. One thrust of the workshop was to learn from these experiences and use the findings to develop more formal, institutionalized means of providing regular and responsive extension assistance to communities. This is linked to the research and field studies that were conducted by a multi-institutional working group that represents group efforts to address complex and multi-sectoral issues. These working experiences and development of initial agreements for cooperative work will be a first step towards improving extension capacity.

CONCLUSIONS

Capacity building in extension methods and linking the capacity building with efforts in the field has been beneficial in establishing the basis of working partnerships between institutions and individuals in Sinaloa for a multitude of community development efforts, including aquaculture. Additional work is needed to continue with the skill building for extension and research professionals. Support in the form of funding and institutional incentives for conducting extension would go a long way towards enhancing the ability of interested professionals to work effectively in aquaculture extension.

ANTICIPATED BENEFITS

Quantitative and qualitative benefits include:

- 75 professionals trained in basic extension methods.
- Leaders and members from 9 communities participated in the training.
- 21 institutions participated in the workshops.
- A learning exchange occurred between aquaculture professionals and those working in other sectors.
- A learning exchange occurred with representatives of three other ACRSP countries (Nicaragua, Honduras, Ecuador).
- Of particular note is that 7 members of CESASIN, the primary aquaculture extension institution in the area were trained in extension.
- Professionals in other sectors were made aware of the benefits of aquaculture for rural communities and the benefits of aquaculture to health.

- Issues related to human health and aquaculture were identified and characterized; this information was incorporated into the associated case studies.
- A gender balance was achieved with 40% of the participants being women.
- Physically disabled individuals (4) participated and later received technical assistance from some of the workshop participants.
- Connections between researchers and extension workers were strengthened or established.
- Extension training materials in Spanish were produced, distributed and made widely available.
- A short video of the workshop was produced by CESASIN and has been shown on local TV channels.
- Results and skills stemming from this workshop greatly enhanced the Human Health case studies.
- Four students from UAS participated in this work directly and two students from UHH contributed to planning and preparation.

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Other support and resources were provided by a large number of host country institutions and their directors. UAS and its faculty oversaw the planning meetings and general logistics for the workshop (Eladio Gaxiola, Guillermo Rodríguez, Nicolás Castañeda). CESASIN (Luis Miguel Aguiar, Director, and Julio Cabanillas) supported planning and execution of the workshop, production of the workshop materials and minutes and provided general coordination. CREDES (Ana Luisa Toscano, Director) provide the workshop venue, dormitory space and food services for the participants. Conservation International (Armando Villalba) also provided support to the workshop logistics and planning. Additional support was also kindly provided by Irma Lorena Camacho López and Ruth María Garduño Gil who volunteered their time to provide oversight of all logistics and arrangements while the workshop was being conducted.

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CIAD also contributed a team of trainers including: María Cristina Chávez Sánchez, Omar Calvario M., Armando García Ortega, Leobardo Montoya Rodríguez, and V. Patricia Domínguez J.

Other trainers included: Benito García, Universidad Autónoma de Nayarit Armando Villalba L. (Conservation International), Emilio Ocha Moreno (Ecocostas), Luis Miguel Aguiar (CESASIN), Armando Vega (Programa Langosta CRIP-La Paz, Nacional Fisheries Institute), Gabriel Cepeda and Armando Nevárez Velásquez (PROJIMO), James Tobey (CRC/URI), Maria Haws (PACRC/UHH), and Ernesto Garmendia (Acuacultura en Sonora).

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The following individuals contributed materials for the workshop or allowed their training materials to be adapted for use: Gary Jensen (USDA/CSREES), John Jacobs (Texas Sea Grant Program), Brian Crawford (CRC/URI), John Supan (LSU Sea Grant Program), and Lisa King (PACRC/UHH). Case studies on extension conducted by the World Bank were also used.

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CONNECTIVITY OF WATER RESOURCE STATUS, ENVIRONMENTAL QUALITY, AQUACULTURE, AND HUMAN HEALTH

Eleventh Work Plan, Aquaculture and Human Health Impacts 2 (11AHHR2)
Final Report

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ABSTRACT

This research attempts to elucidate relationships between human health, water resources, and aquaculture status and development in the States of Sinaloa and Nayarit, Pacific Mexico Coast. Water quality and the volume available for aquaculture and coastal habitat conservation were found to be deteriorating, adversely affecting aquaculture through chemical, bacterial, and viral contamination. Solid waste disposal by communities and industry is affecting human health and may limit opportunities to establish aquaculture. Impacts caused by aquaculture activities are minimal and are limited to shrimp farms. Water availability is also decreasing due to prioritization of other economic activities, which affects reservoir fisheries and aquaculture, as well as changing water quality in downstream shellfish growing areas. Poor water quality may affect the future expansion of shellfish culture and threatens the existing industry. Gnathostomosis is an emerging health issue and can impact communities farming freshwater fish. Greater awareness is needed for

all stakeholders, as is support for community-based health, development and aquaculture initiatives. Improved extension services have been key in past successes and more attention is required in this area for aquaculture to succeed.

INTRODUCTION

Water resources are fundamental aspects of conservation, development, and aquaculture. The Pacific coast of Mexico on the Gulf of California is a region rich in aquatic and terrestrial resources of great importance to Mexico and the United States. The coastal States of Sonora, Sinalo and Nayarit are of political and economic importance to Mexico and the US (Figure 1). The thriving marine and coastal fisheries supply internal demand for fisheries products and represent an important source of foreign export. The three states are the sites of major agricultural activity supplying much of the agricultural produce imported to the US. The Sierra Madre, which runs the length of Western Mexico supports opium and marijuana cultivation.

Figure 1: The Gulf of California and the locations of Sonora, Sinaloa, and Nayarit States.

Bahia Santa Maria (BSM) encompasses an area of 50,000 ha of wetlands and is surrounded by communities that make their living fishing, farming, and by laboring on large agroindustrial and aquaculture (shrimp) operations. Three rapidly growing municipalities surround the Bay (Angostura, Ahome, and Navolato). A major city, Culiacan and a number of medium size cities and towns are increasingly encroaching on the agricultural and wetlands areas.

BSM has been the target of national and international conservation and integrated coastal zone management efforts since 1997, primarily catalyzed by the Universidad Autonoma de Sinaloa (UAS) and Conservation International, along with US partners such as the Coastal Resources Center of the University of Rhode Island and more recently, the Pacific Aquaculture and Coastal Resources Center of the University of Hawaii, Hilo. These efforts culminated in development of a Bay Management plan in 2000 and formation of a tri-municipal Conservation and Development Committee legally charged with implementing the management plan in 2004. A number of community-based development efforts were also initiated including community sanitation drives, latrine installation, composting, co-management of the crab fishery, development of sportfishing as an alternative, use of fisheries products to make fish and shrimp meal, and oyster cultivation.

The presence of a major and growing shrimp industry around BSM also prompted the collaborating group's interest in aquaculture. A major multi-institutional effort funded by USAID, Conservation International and the David and Lucille Packard Foundation led to joint efforts with the social and private-sector shrimp farmers to research and develop best management practices for shrimp farming.

Learning from the success in BSM, Conservation International then pioneered similar efforts in Marisma Nacionales, State of Nayarit. This area was included in the case studies because it is the principal site of culture for the native oyster species (*Crassostrea corteziensis*). Further, information exchange had taken place between women's groups in BSM, which were beginning oyster culture, and the groups in Nayarit, which were experienced with oyster culture.

At this point, two new perspectives arose among the stakeholder communities and the collaborating group of institutions. First, the potential for alternative forms of aquaculture and mariculture became increasingly attractive to the groups as a sustainable way to utilize available bay and watershed resources. Shrimp farming and other forms of aquaculture were already important in the coastal areas. It was clear however, that major resource, technical, and social challenges existed. Second, while previous efforts were largely coastal in their emphasis, the need to work within a watershed context was becoming increasingly clear. Thus, the ACRSP Human Health and Aquaculture grant was an opportunity to: 1) begin implementing one component (diversification of aquaculture for the benefit of coastal communities) of the management plan, 2) develop a multi-institutional extension delivery strategy to support these efforts, and 3) conduct research aimed at elucidating key aspects of aquaculture development and human health (i.e., the three Human Health and Aquaculture Case Studies). The three Human Health and Aquaculture Case studies examined three theme areas judged to be of importance to aquaculture development in the context of human and environmental health: 1) water resources, 2) dimensions of social participation, and 3) sanitation and food safety and quality.

This case study achieves the following:

- Assesses the current status of freshwater, brackishwater, and saltwater resources and examines relevant trends.
- Elucidates linkages between water, community health, and aquaculture.
- Characterizes the major threats and challenges related to water resources affecting human health, the environment, and aquaculture.
- Makes recommendations to address key issues from the perspectives of aquaculture development, watershed management, coastal zone management and improvement of public health.
- Makes recommendations for future work.

METHODS AND MATERIALS

Case study research began in March 2004 with a joint meeting of the Collaborative Group in Culiacán, Mexico at the Autonomous University of Sinaloa. The principal Mexican public institutions involved in this work were the Universidad Autonoma de Sinaloa (UAS), Comite Estatal de Sanidad de Sinaloa (CESASIN), Centro de Investigacion Alimentaria y Desarrollo/Mazatlán (CIAD), Universidad Autonoma de Nayarit, Conservation Internacional. US universities involved in this work include the Pacific Aquaculture and Coastal Resources Center/University of Hawaii-Hilo (PACRC/UHH), Coastal Resources Center/University of Rhode Island (CRC/URI), Louisiana State University Sea Grant Program (LSU), and the University of Hawaii Sea Grant College Program.

The research involved close coordination with social and private sector stakeholders that were engaged in aquaculture, were planning on starting aquaculture projects, or community groups working on other forms of alternative livelihoods. Most of these groups had long-standing ties with the collaborating group vis-à-vis the long-term conservation and management efforts. One new group engaged in this work is PROJIMO, an NGO operated by and for the physically handicapped, which engages in economic, health and social development work.

Twenty-one principal researchers from Mexico, Ecuador, and the US conducted research as the basis of the case studies including specialists in: biology, aquaculture; aquatic pathology; fisheries; nutrition; public health; architecture; coastal management; community, urban, and regional planning; gender; conservation; economics; sociology; and political science. Six students were also involved in the research and two of them incorporated research results into their theses. Research was conducted through literature review, site visits and observations, and stakeholder interviews over a period of 14 months. Most of the site visits included a component of training or outreach in topics related to aquaculture development, management or health issues, including shellfish sanitation. The collaborating group met on a regular basis to share findings, mutually review and critique materials and to draft the final document in late 2005.

The research sites were selected based on three criteria:

- The presence of communities that had been involved in long-term conservation and management efforts that included some aspect of aquaculture.
- The site has economic, social, and conservation significance to the region.
- The site exemplifies issues related to aquaculture development in the region.

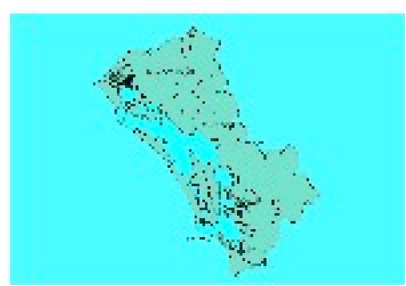
Thus, BSM and two of its fishing communities, Playa Colorada and La Reforma were chosen since BSM is a major wetlands and conservation site located near agricultural and urban areas. BSM is surrounded by an extensive watershed that is the site of rapid urbanization and highly developed agro-industry. Playa Colorada, along with other BSM communities such as La Reforma, has been involved in the group's conservation and management efforts. Well-established women's and cooperative groups are conducting a wide range of economic and development activities, including aquaculture. The Mocorito River and adjacent watershed, which feed BSM, are sites of freshwater aquaculture and intensive agriculture, thus providing an opportunity to study water resources, human health and aquaculture. Boca Camichin is a comarca (county) in the State of Nayarit encompassing important agricultural, wetlands, fisheries, and oyster aquaculture areas, and is also an indigenous area. Similar to BSM, the wetlands in Boca Camichin (Marisma Nacionales) are the subject of multi-institutional efforts in conservation and natural resources management. A fourth study focus is the group PROJIMO, which has various branches, located in Coyotitan and Durangito de Dimas. The group itself is the subject of interest, not its surroundings, so it may suffice to mention that the Western Sierra Madre (Sierra Madre Occidental) which runs along most of the Pacific Coast of Mexico to the southern US is a primary site for cultivation of opium poppies and marijuana, as well as a major drug transportation route into the US. Drug-related culture and violence permeate the Western coastal states of Mexico, and has a direct relationship with the high rate of handicapped persons in these areas.

Site Descriptions

1. Bahía Santa María

The State of Sinloa is the site of important fisheries and aquaculture activities being the largest producer of fisheries products in terms of revenue, the second in volume and the major site of shrimp farming. It possesses numerous bays, coastal lagoons, rivers, and dams. The State has 656 km of coastline with 221,600 ha of coastal lagoons. Bahia Santa Maria (Figure 2) is the largest bay in the State having 50,000 ha of wetland area. It is connected to the Gulf of California by two mouths.

Figure 2. Location of Santa Maria Bay within the State of Sinaloa and the structure of the Bay including its two component lagoons, Playa Colorada and La Reforma.



BSM encompasses two major coastal lagoons, Playa Colorado (6,000 ha) to the north and Santa Maria-La Reforma (47,000 ha) to the south, 153 islands, 25 estuaries, and 3 bays (Figure 2). The fisheries resources of the bay are rich and include snapper, bass, snook, mullet, and other species.

Shrimp, which is fished for 6 months annually, is the principal fisheries resource, and crab is also important.

The freshwater for the system comes from diverse sources, including the Mocosito River, which is 19.1 km in length. The abundant freshwater is the basis of agriculture, the principal activity of most of the communities, which rely on seasonal and irrigated forms of agriculture. The lower watershed is where river fisheries are the principal resource for five communities: Dautillos, Yameto, La Reforma, Costa Azul, and Playa Colorada. There are 66 shrimp farms totaling 9,000 ha found in the brackish water areas behind the mangrove zone in the Muncipalities of Angostura and Navolato. Duck hunting and salt-production are also important economic activities.

Within Bahia Santa Maria, the communities of Playa Colorada and La Reforma were chosen to participate in this study. The communities of La Reforma and Playa Colorada have been involved with conservation, management and development efforts for over ten years and have achieved success with diverse efforts including community sanitation works, co-management of the crab fishery, development of sportfishing, and environmental education efforts.

2. Eustaquio Buelna Reservoir

The Mocorito River is a major source of freshwater for Santa Maria Bay and flows directly into Playa Colorada Bay. Much of the water produced (158 Mm^3 annually) in this watershed is captured by the Estaquio Buelna Reservoir, which became effective in 1981 (Figure 3). The watershed includes many of the major, growing cities and towns in Sinaloa. The reservoir has a capacity of 343.8 million Mm^3 and annually supplies 104.8 Mm^3, mostly for irrigation and cattle production. The reservoir is critical to the State, providing hydroelectric power, irrigation, sportfishing, commercial fishing and recreation. It was chosen as a representative study site for the 5 similar reservoirs in Sinaloa. Of interest in this research are the fishing and aquaculture cooperatives utilizing the reservoir. The reservoir is stocked with catfish, tilapia, and bass. The fishing cooperatives harvest the fish and have been making efforts to begin aquaculture in pens as is done in other reservoirs. The reservoir fishing and aquaculture throughout the state is facing increasing problems of decreasing water volume, fish sizes, and fish abundance.

Figure 3. Fishing and fish culture site in Eustaquio Buelna Reservoir.

3. Boca de Camichín

The areas known as Marismas Nacionales (National Marshes) where Boca de Camichin is located, is situated in the northeastern part of the State of Nayarit. This physically complex wetlands area has a surface area of 200,000 ha and constitutes an important area of wetlands, lagoons, and mangroves. Approximate 15% of the mangroves and 20% of the estuarine area of the nation is found in here. The area is also home to four major indigenous groups. Boca de Camichin is located at the mouth of the San Pedro River.

Figure 4. Location and aerial photograph of Boca de Camichín.

Local communities primarily dedicated to river fisheries have been cultivating a native species of oyster (*Crassostrea corteziensis*) for 35 years using floating rafts. The culture area covers 300 ha with 1,200 rafts, involves 800 people, and generates an estimated $15,000,000.00 pesos annually.

Figure 5. Oyster culture at Boca de Camichín.

RESULTS

Pressure on water resources is impacting both water quality and the volume of water available for aquaculture and conservation. Utilization of freshwater in the region is largely dedicated to satisfying urban and agricultural needs, with much of the volume being diverted to these areas leaving downstream areas and reservoirs increasingly short of water. This is exacerbated by the fact that most of the Pacific coast has a semi-arid climate and rainfall is seasonal. In the case of the reservoir fisheries and the increasing cultivation of tilapia in the State's six major reservoirs, production is threatened by seasonal drying of large areas of the reservoir. Recent below average rainfall has made the situation worse for the reservoirs fisheries and aquaculture projects. The need to maintain water levels for aquaculture is not recognized by reservoir managers. Reduction in freshwater flows also affects the coastal bays and lagoon by increasing salinity and reducing the scouring action of seasonal downpours and floods. This may impact shrimp culture located in these areas since higher salinity and higher temperature may increase vulnerability to disease. The shrimp farms themselves contribute to deterioration of water quality and community sanitation by releasing organic nutrients into bays and lagoons, and in some cases, dumping solid wastes in wetland areas. This scenario appears to be improving with an increasing awareness of best management practices and the tendency to reduce feeding, fertilization and pumping rates.

An important issue uncovered during the research is that almost all forms of freshwater aquaculture are greatly impeded by scarcity of fingerlings including tilapia, catfish, and bass. For bivalve cultivation, the other most promising form of aquaculture, seed is also difficult to obtain in the case of oysters and clams due to lack of local hatcheries, and the newer species under development such as penshells (*Atrina maura*) are not available through commercial sources of seed.

Point-source and non-point source pollution is also impacting the entire watershed. First, community sanitation, while generally improving over the last ten years, leaves much to be desired. Particularly in the poorer and more remote coastal communities, many homes still do not have running water or toilets. The number of latrines is increasing, but may contribute to water pollution if not properly situated and constructed. In the case of communities that have municipal water and sewage, wastewater treatment is generally present but often inadequate. This is particularly true of larger cities such as Culiacan, where much of the waste enters the watershed after only minimal treatment. Some of the coastal communities have improved their local situation through community efforts to build latrines, conduct community trash collection and observe sanitary standards, but even so, have little control over external sources of contamination.

High levels of bacteria, viruses and organic nutrients have particular importance to bivalve cultivation. Approximately 70% of the bivalves fished or grown in the region do not meet sanitary requirements. Lack of potable water clearly affects human health in many areas, and also means that the harvesting, handling and processing of aquaculture products cannot meet sanitary standards. This includes the quality of ice used for storing the products. Agriculture and animal husbandry are also impacting water quality significantly; organophosphates were found in levels exceeding standards in Bahia Santa Maria and in areas adjacent to Mazatlan. Cattle rearing and slaughtering facilities, common in Sinaloa, also release liquid and solid wastes directly into streams and rivers with visibly obvious impacts.

Aside from the human health problems associated with drinking contaminated water and using it to process aquatic products, another health issue that is emerging as important to the region is that of the nematode infection gnathostomosis. Freshwater and brackishwater fishes are hosts during part of the life cycle of this parasite and when ingested by humans, cause a range of symptoms, some of which result in death, stroke or disfigurement. The incidence of this disease and the geographic range of the parasite are increasing. Increased aquaculture production, particularly of tilapia and other freshwater fishes, combined with lack of awareness and the traditional practice of consuming raw aquatic products is aiding in the spread of the disease.

Other results include:

- Two multi-sectoral planning meetings were held to prepare for the workshop and were also used as opportunities to work on the Human Health and Aquaculture case studies.
- Training was provided to 75 professionals from various development sectors and other ACRSP countries or from the SUCCESS projects. Many participants have continued to use the acquired skills in their extension efforts.
- Training materials from the workshop were compiled on a CD, which was provided to all 75 participants and distributed to another 20 stakeholders. Materials have also been posted the PACRC/UHH website to increase accessibility.
- The training materials are also being used for training in the five-year extension training effort that is taking place under sponsorship of the USAID/EGAT SUCCESS project. Specifically, materials have been used in Nicaragua, Ecuador, and Tanzania training workshops.
- Stronger institutional ties are being formed between the various institutions working together on ACRSP and related efforts. Specifically, UAS, UAN, CIAD, and CESASIN are working in a much more coordinated fashion to deliver extension and research services. Ties with US universities and institutions such as Sea Grant are being strengthened.
- CESASIN, the quasi-governmental agency responsible for aquaculture sanitation in Sinaloa, which focuses largely on shrimp farming, has decided to expand its services (extension, diagnostic laboratory) to shellfish producers and to also convene a shellfish producers' steering committee.

DISCUSSION

Human health is clearly impacted by the general deterioration of water quality in the region. Mexico has adequate policy and regulatory protection, but implementation and enforcement are the issues in the case of contamination by industrial, urban, and agricultural concerns. The poorer coastal communities and rural municipalities are often prevented from taking necessary measures due to lack of resources. Community-based clean up efforts aimed at improving sanitation have proven effective for several communities located around Bahia Santa Maria. However, it is clear that financial and technical support, similar to that provided by UAS and Conservation International are key pre-conditions to success. Enforcement is also required in the case of urban areas or industrial concerns that violate regulations and standards.

Poor water quality is a serious concern as aquaculture grows and interest in brackishwater and freshwater alternatives to shrimp farming increases. Particularly for bivalves grown in coastal areas, careful attention needs to be paid to selecting culture areas that are clean enough to produce safe, high quality shellfish. Although Mexico has adequate regulation and policy for shellfish sanitation, which is analogous to that of the US, implementation and capacity to classify and monitor shellfish growing areas is lacking. This will be the focus of the Year 12 ACRSP Human Health and Aquaculture Workplan. As shellfish farming becomes a viable economic alternative in more coastal areas, such as has happened in Nayarit, measures need to be taken to protect what is expected to be a rather limited range of areas suitable for shellfish culture as coastal urbanization, agricultural and industrial activities continue to boom in Pacific Mexico.

A great deal of work is also needed in the areas of awareness and skill building in product quality, safety and sanitation. This work would help protect human health and improve the quality and shelf life of products. Further it will extend the range of marketing possibilities beyond the immediate vicinity of the farm. This topic is dealt with in greater detail in Case Study 3, "Food Safety and Handling: Increasing Local Consumption of Aquaculture Products and Improving Quality".

All efforts to improve the situation require better delivery of extension services, another aspect of the Human Health and Aquaculture project. A major lesson learned is that successful community development of aquaculture and health projects have relied on extension services, usually provided by multiple partners. If the extension methods and approaches applied during past work by the collaborating group are applied to aquaculture and human health efforts, it will greatly improve their chances of success.

CONCLUSIONS

Human health, aquaculture and environmental quality are inextricably linked. Aquaculture offers much potential to improve food security, revenues, employment opportunities, and potentially offers alternatives to fishing and other extractive activities. It may even offer some individuals the opportunity to remain in their coastal villages by reducing the attraction of emigration or involvement in the drug trade. Successful aquaculture development beyond current levels will require careful attention to understanding and maintaining water quality, positioning aquaculture as deserving of water allocations, integrating development efforts into wider community development and watershed management efforts, and integration of stakeholders and institutions not commonly involved in this field. Improved multi-institutional extension services delivery is also a key to success. Equally important is working to remove key impediments such as a lack of financing, fingerling and seed sources, and transfer of technology.

ANTICIPATED BENEFITS

Quantitative and qualitative benefits include:

- Improved understanding and data available for key technical issues related to human health, aquaculture and fisheries detailed in a 150-page book.
- 75 professionals trained in advanced extension methods and aquaculture skills.
- Leaders and members from 5 communities participated in the training.
- 22 institutions participated in the workshops.
- Training materials from the workshop have subsequently been used in three other ACRSP/SUCCESS sites (Nicaragua, Ecuador, and Tanzania).
- Of particular note is that 8 members of CESASIN, the primary aquaculture extension institution in the region, received further training.
- CESASIN has decided to expand its extension coverage to the shellfish sector.
- Professionals in other sectors were made aware of the benefits of aquaculture for rural communities and the benefits to health.
- Issues related to human health and aquaculture were identified and characterized; this information was incorporated into the associated case studies.
- A gender balance was achieved with 45% of the participants being women.
- Connections between researchers and extension workers were strengthened or established.
- Extension training materials in Spanish were produced, distributed and made widely available.
- Results and skills stemming from this workshop greatly enhanced the Human Health case studies and two ACRSP investigations.
- Four students from UAS participated in this work directly and two students from UHH contributed to planning and preparation.

ACKNOWLEDGMENTS

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ANALYSIS OF CRITICAL POINTS IN AQUACULTURE PRODUCTION AFFECTING PARTICIPATION AND LEVEL OF BENEFITS TO WOMEN, YOUTH, AND DISADVANTAGED STAKEHOLDERS

Eleventh Work Plan, Aquaculture and Human Health Impacts 3 (11AHHR3)
Final Report

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ABSTRACT

This work assessed the level of participation in, and benefits derived from aquaculture for women, minority groups and handicapped individuals in Sinaloa and Nayarit, Mexico. Shrimp farming, the most important form of aquaculture in the region, was perceived by members of surrounding communities as offering, at best, a mix of benefits and negative impacts, despite clear economic benefits to the regional economy. For other forms of aquaculture, participation by women and minority groups is limited. Often their participation is limited to playing a supporting role to male family members and they do not have decision-making power. However, all groups that were

interviewed expressed positive attitudes towards greater inclusion of women and minority groups. Two models of participation by women and handicapped individuals are discussed in this work: 1) oyster cultivation cooperatives of Nayarit, and 2) PROJIMO, an NGO operated by and for handicapped individuals. Lessons learned for future aquaculture development initiatives are detailed.

INTRODUCTION

Aquaculture is an important activity in the Pacific Mexico States where shrimp, finfish, and bivalves are cultured. Shrimp farming is the largest industry and one, which requires large amounts of labor, particularly for processing. Shrimp farming and its effect on community wellbeing was an important topic during development of the Bahia Santa Maria (BSM) Bay Management Plan and related community development activities. The communities in and around BSM also engage in finfish culture in reservoirs and were interested in establishing bivalve culture in the bay, using the successful establishment of oyster culture by community groups in Nayarit as a model. One component of the BSM Management Plan is development and implementation of Best Management Practices (BMPs) for shrimp farming. The coordinating group worked with the private and social sectors engaged in shrimp farming to assess gaps in management practices and develop a set of BMPs. It became clear during this work that shrimp farming offered both benefits to the coastal communities, and at the same time posed risks and impacts.

As a result of Conservation International's effort to transfer the Bay Management model to the Marismas Nationales, ties between BSM stakeholder groups and similar groups began to emerge. Further, transfer of knowledge took place between communities cultivating oysters and women's groups in BSM.

Based on the common goals of diversifying aquaculture to forms other than shrimp and improving direct benefits to the communities, stakeholders and collaborating groups began to assess which forms of aquaculture were most suitable for communities to adopt. Questions about the means of improving the degree of participation of traditionally marginalized groups such as women; minorities, elderly and handicapped also began to emerge. Women's groups in BSM have been instrumental in conservation efforts, community organization, public health-drives, and fisheries co-management (Figure 1). The role of women in other forms of aquaculture than shrimp was also of interest, so research was conducted in the oyster growing communities of Boca Camichin, State of Nayarit, and at the Eustaquio Buelna Reservoir, located in the Rio Mocorito, which flows into BSM.

Figure 1. Playa Colorada women's group engaged in community composting and sanitation activities.

Mexico has a growing number of handicapped individuals due to a variety of factors, including drug and gang related violence. Mexico has suffered from increasing rates of violent crime, with the rate of violent crime increasing 90% from 1985 to 1996 from 10.2 to 19.6 per 100,000. Mexico is second only to Columbia in the Americas in the rate of homicide, with a present rate of 12.6 per 100,000 being committed per year. The area is also home to dozens of groups of indigenous people who traditionally benefited less from economic development than other groups. To this end, the NGO PROJIMO, located in the foothills of the Sierra Madre in southern Sinaloa, was asked to participate in this work. PROJIMO is a collection of groups of handicapped individuals working and training in vocational skills, medical therapy, and manufacturing of wheel chairs (Figure 2). It was believed that their success at self-organization and development of alternative livelihoods could inform these efforts.

Figure 2: Activities conducted by PROJIMO including manufacture of wheel chairs, training and medical therapy.

This case study achieves the following:

- Analyzes the role of women in the predominant form of aquaculture in Pacific Mexico (shrimp culture) to characterize and quantify their modes of participation, degree of benefits received, and the affect of these factors on food security and human health for women and their families.
- Analyzes the role of women in the culture of other species.
- Assesses the feasibility of targeting disadvantaged youth and individuals with physical and mental disabilities in rural communities for involvement in aquaculture.
- Identifies the next steps required to implement recommendations stemming from this work.

METHODS AND MATERIALS

Case study research began in March 2004 with a joint meeting of the Collaborative Group in Culiacán, Mexico at the Autonomous University of Sinaloa. The principal Mexican public institutions involved in this work are the Universidad Autonoma de Sinaloa (UAS), Comite Estatal de Sanidad de Sinaloa (CESASIN), Centro de Investigacion Alimentaria y Desarrollo/Mazatlán (CIAD), Universidad Autonoma de Nayarit, Conservation Internacional. US universities involved in this work include the Pacific Aquaculture and Coastal Resources Center/University of Hawaii-Hilo (PACRC/UHH), and the Coastal Resources Center/University of Rhode Island (CRC/URI).

The research involved close coordination with social and private sector stakeholders that were engaged in aquaculture, were planning on starting aquaculture projects, or community groups working on other forms of alternative livelihoods. Most of these groups had long-standing ties with the collaborating group vis-à-vis the long-term conservation and management efforts. One new group engaged in this work is PROJIMO, an NGO operated by and for the physically handicapped.

Twenty-one principal researchers from Mexico, Ecuador, and the US conducted research as the basis of the case studies including specialists in: biology, aquaculture; aquatic pathology; fisheries; nutrition; public health; architecture; coastal management; community, urban and regional planning; gender; conservation; economics; sociology; and political science. Six students were also involved in the research with two of them incorporating research findings into their theses. Research was conducted through literature review, site visits and observations, and stakeholder interviews over a period of 14 months. Most of the site visits included a component of training or outreach in topics related to aquaculture development, management or health issues, including shellfish sanitation. The collaborating group met on a regular basis to share findings, mutually review and critique materials and to draft the final document in late 2005.

The research sites were chosen based on three criteria:

- The presence of communities that had been involved in long-term conservation and management efforts that included some aspect of aquaculture and/or fisheries.
- The site has economic, social and conservation significance to the region.
- The site exemplifies issues related to aquaculture development in the region.

Thus, BSM and two of its fishing communities, Playa Colorada and La Reforma were chosen since BSM is a major wetland and conservation site located near agricultural and urban areas. BSM is surrounded by an extensive watershed that is the site of rapid urbanization and highly developed agro-industry. Playa Colorada, along with other BSM communities such as La Reforma, has been involved in the group's conservation and management efforts. Well-established women's and cooperative groups are conducting a wide range of economic and development activities, including aquaculture. The Mocorito River and adjacent watershed, which feed BSM, are sites of freshwater aquaculture and intensive agriculture, thus providing an opportunity to study water resources, human health and aquaculture. Boca Camichin is a comarca (county) in the State of Nayarit encompassing important agricultural, wetlands, fisheries and oyster aquaculture areas, and is also an indigenous area. Similar to BSM, the wetlands in Boca Camichin (Marisma Nacionales) are the subject of multi-institutional efforts in conservation and natural resources management. A fourth study focus is the group PROJIMO, which has various branches that are located in Coyotitan and Durangito de Dimas. The group itself is the subject of interest, not its surrounding, so it may suffice to mention that the Western Sierra Madre (Sierra Madre Occidental) which runs along most of the Pacific Coast of Mexico to the southern US is a primary site for cultivation of opium poppies and marijuana, as well as a major drug transportation route into the US. Drug-related culture and violence permeate the Western coastal states of Mexico, and has a direct relationship with the high rate of handicapped persons in these areas.

RESULTS

A review of Mexico policy and regulation demonstrates that in general, Mexican law promotes inclusion and equity of women and minority groups in all economic and social activities. There also tends to be a generally high awareness among professionals working in the development field of gender and equity issues. Realization of full participation, however, lags behind the supporting legal framework. In general, the participation of minority groups in aquaculture has been marginal. However, in contrast to fishing, women, elderly, and children pay a visible and significant role in activities related to harvest and processing of aquaculture products. Although men dominate most of the productive activities associated with aquaculture such as shrimp and oyster culture on the coast and finfish in freshwater areas, members of minority groups share in the processing, commercialization, and business management. Today women are the majority players in processing, storing, and packing fisheries products such as oysters and shrimp. Further, women are seldom employed as wage employees, temporary or long-term. Their labor, however, is often not recognized socially or even in economic terms. Their work is often considered "in support" of a man, and generally is not considered in decision-making. In the case of male children or elders, their functions are also viewed as being supportive, for learning or as a minor occupation, with little or no payment.

Shrimp farming

Aquaculture, particularly shrimp farming, is an activity that is very important for Sinaloa and Sonora, but is perceived by many as not having a significant impact on the well-being of the coastal communities, much less minority groups, with the exception of a few examples. Most communities located close to shrimp farms do not perceive that the economic returns generated by shrimp farming benefit them; others expressed the view that at least some benefits are derived. Some perceive mixed outcomes with limited benefits but with the bulk of the impacts being negative. From the beginning of aquaculture development, the coastal fishing communities have viewed aquaculture as something coming from the outside, an activity not related to fishing and even worse, associated it with negative impacts on fisheries such as water pollution and the extraction of postlarve for stocking ponds. For this reason, many fishers associate reduction in fisheries catches with the presence of shrimp farming.

Before 1986, shrimp was a species reserved exclusively for exploitation by cooperatives. After later legal changes permitted purchasing of ejido property and allowed commerce in shrimp postlarvae, construction of shrimp ponds began to radically change the landscape of coastal areas, use of resources, and ecological processes on different spatial scales.

The perception by coastal communities of the impact of shrimp culture in the social well-being of coastal habitants can be explained by the following factors:

- The owners of shrimp ponds do not integrate themselves into local communities as they do not live there. In fact, many farmers who originally come from the communities later move to the cities.
- The owners usually only visit sporadically, during harvests or stocking.
- Shrimp farmers do not appear to link the living conditions in the communities with their businesses. In general, they appear to maintain relationships only with a few selected local authorities to gain particular favors.
- Laborers from outside the communities are often preferred with the rationalization of avoiding theft or to avoid hiring fishers who may leave to fish.
- It is often difficult for the community to determine who the owner is and establish a relationship with him.
- Access to shrimp farms is usually restricted for reasons of biosecurity. The farms appear to the community to be a "world apart" and have little to do with community life.

In BSM, shrimp farms often try to offer the lowest paid positions to minority groups, particularly women and elderly people. Despite this, the shrimp farmers say they are willing and have a favorable opinion towards establishing better relationships with the communities and wish to generate opportunities for these groups if possible.

Alternative forms of aquaculture

Despite the rather negative view of shrimp culture by poor coastal communities, many still express interest in small-scale aquaculture and have development plans. The conditions in the communities of BSM, the relationships and closeness with aquatic resources and the ties with external institutions have allowed organized groups in Playa Colorada and La Reforma to see aquaculture as a complementary form of family income, a way to better their nutrition, well-being and quality of life, and in the medium-term, to better control use of resources and space, as well as to participate in decision-making processes. Accordingly, community groups have developed plans for aquaculture projects (oyster and clam culture, alternative uses for fish and shrimp waste) and other activities related to community welfare such as tourism, a community kitchen, and garbage collection. These groups are self-mobilizing for economic and sociocultural reasons, they control their own roles, participate as partners, citizens and through representatives to act proactively to obtain their objectives. Experience gained from these activities is viewed as establishing the preconditions for success in other fields, such as aquaculture development.

The role of external forces is key to accessing resources for minority groups. For example, government programs, research and development projects, and related efforts of NGOs and civil organizations may all facilitate development. Extension assistance is also a key to their involvement and ultimate success.

Oyster culture

Culture of oysters in Nayarit by fishing communities similar to those found in Playa Colorada and La Reforma has resulted in a positive impact on social well-being and self-perception. Key to this is the fact that community members initiated oyster culture, belongs to them and is controlled by them. While men play the key role in productive activities, women and other minority groups also participate regularly. Women are also the clear beneficiaries of processing and commercialization activities. Interviews show that community members in Boca de Camichin believe that their high

rate of home ownership and availability of services such as power and water are due to the economic impact of the small oyster farms. Women appear to have been empowered through their roles as oyster vendors and processors, and in fact often attend regional and national events related to gender and natural resources. They have a high level of control over the returns from their work and are able to spend this for the good of the family. The success in Nayarit is generally viewed by other communities such as La Reforma and Playa Colorada as a model they wish to emulate. This has led to exchanges between the communities with BSM communities offering expertise in natural resources management and the Boca de Camichin offering their experience with small-scale oyster culture. The Nayarit oyster farmers do suffer from challenges and obstacles, however, such as sanitation, transport, processing, and marketing issues. This is more fully detailed in Case Study #3, and had led to the Workplan 12 activities being centered around bivalve culture issues.

Freshwater fish culture in reservoirs

In general, the fishing cooperatives that are growing fish or that wish to establish fish culture projects are dominated by men who do most of the fishing and transportation. They also control the commercialization although usually the fisher sells the fish to a middleman who picks up the fish at the reservoir's edge. The main role of women and the few minority group individuals is in heading and filleting the fish. In most cases they are not members of the cooperative, but are spouses or family of cooperative members, so do not have a role in cooperative decision-making. One of the primary challenges expressed by fishers is the low price they are forced to accept from the fish buyers. If women could be enabled through training and possibly financing to engage in commercialization of the fish as is done in oyster culture, more control and revenues might accrue to the women and possibly also benefit the fishers through retaining revenues within the local families. The male cooperative members did express overall positive views towards inclusion of women and minority members.

PROJIMO and handicapped individuals

PROJIMO provides one of the best examples of what participatory methods and community empowerment can achieve. PROJIMO was self-organizing and although it has received support from international and local funding agencies and technical assistance providers, the members have insisted on maintaining full control and decision-making power over all aspects of their work. Their motto "nothing about us without us" has been put into action. Their efforts to establish activities to generate income and occupations for their handicapped members have been highly successful and include training in medical therapy, construction of wheelchairs, fabrication of prosthetics, and teaching Spanish to foreigners. As a model of community and individual capacity building, they have excelled. In terms of increasing participation by handicapped persons in aquaculture, outcomes were less clear. The PROJIMO members wish to build and operate a tilapia pond, and if financial resources become available, it seems probable they will succeed at this as they have already accomplished more challenging tasks. Whether aquaculture is economically or biologically feasible in their communities is not certain (due to water shortages). One disadvantage is that their remote location in an area notorious for drug related activity impedes them accessing technical assistance. This is true of many rural groups as there are simply areas in Sinaloa that few people will risk traveling to.

For handicapped individuals that are not part of an organized groups such as PROJIMO, fuller participation in aquaculture or any economic activity will require changing people's attitudes regarding the abilities of such persons, and providing training, support and medical services that makes it possible for handicapped individuals to participate fully in life's activities. While the situation is improving in Mexico, improvement in rural, impoverished communities may be slow. However, those professionals working in aquaculture development can at least keep this issue to the forefront and look for opportunities to involve the handicapped. The exposure of collaborating group to the example set by PROJIMO had a profound effect on the group's awareness of, and interest in trying to include more handicapped in all of the groups conservation, development and educational efforts.

DISCUSSION

Despite the fact that the coordinating group has extensive experience with the community groups involved in this study, valuable lessons were learned. First, it became clear that public institutions and NGOs that have played a role in the control and utilization of natural resources often have played a double role. On one hand, they support community actions through facilitation of permits, financing and training, but at the same time they may sabotage self-organization and create dependency, lend themselves to corruption and selectively support certain stakeholder groups. New roles and new methods are required to improve this situation. Some useful models have been observed during the work, for example those that emphasized full participatory approaches with the communities driving the decision-making process. These can be taken as lessons for future action, particularly in promoting aquaculture development.

Increasing the participation of women and minority groups will depend on resources availability, awareness as to their rights and ability to contribute fully, capacity building, and increased access to services from public institution. Enabling handicapped individuals to participate more fully in aquaculture is still a challenge, but more effort should be dedicated to this as handicapped individuals can be assets to aquaculture operations and occupations that lend themselves to improved self-image and economic empowerment are necessary. PROJIMO provides a good model and partnership with this group could facilitate future efforts with other groups or individuals.

Shrimp culture continues to be the primary form of aquaculture in the region, and if shrimp farmers were to develop better relationships with the surrounding communities, the following steps would probably be necessary:

- Employment of more community members
- Wage increases
- Supporting community programs and projects
- Better conflict resolution between the farms and the community
- Better implementation of BMPs such as improved solid waste disposal

CONCLUSIONS

Although participation by women and minority groups has been relatively limited in aquaculture, two outstanding models were found: 1) the oyster culture communities of Nayarit; and 2) PROJIMO. Both technical and methodological lessons learned during this research will benefit the collaborating group and community stakeholders in future aquaculture development.

ANTICIPATED BENEFITS

Quantitative and qualitative benefits include:

- Improved understanding and data available for key technical issues related to human health, aquaculture, and fisheries detailed in a 150 page book.
- Improved understanding of the potential for involvement of handicapped individuals in aquaculture and a good model presented by PROJIMO for how this could be done.
- 75 professionals trained in advanced extension methods and aquaculture skills.
- Leaders and members from 5 communities participated in the training.
- 22 institutions participated in the workshops.
- Training materials from the workshop have subsequently been used in three other ACRSP/SUCCESS sites (Nicaragua, Ecuador, and Tanzania).
- Of particular note is that 8 members of CESASIN, the primary aquaculture extension institution in the region, received further training.
- CESASIN has decided to expand its extension coverage to the shellfish sector.

- Professionals in other sectors were made aware of the benefits of aquaculture for rural communities and the benefits to health.
- Issues related to human health and aquaculture were identified and characterized; this information was incorporated into the associated case studies.
- A gender balance was achieved with 45% of the participants being women.
- Connections between researchers and extension workers were strengthened or established.
- Extension training materials in Spanish were produced, distributed and made widely available.
- Results and skills stemming from this workshop greatly enhanced the Human Health case studies and two ACRSP investigations.
- Four students from UAS participated in this work directly and two students from UHH contributed to planning and preparation.

ACKNOWLEDGMENTS

Funding was generously provided by: ACRSP; the David and Lucille Packard Foundation via a grant to the Coastal Resources Center/University of Rhode Island; the Office of the Chancellor, Autonomous University of Sinaloa; University of Hawaii-Hilo; and USAID/Mexico. Thanks are given to the individuals within these institutions who supported these efforts: Hillary Egna (ACRSP); Pam Rubinoff and James Tobey (CRC/URI); Rose Tseng and Christopher Lu, UHH; Kevin Hopkins (PACRC/URI); Gómer Monárrez González, Ambrocio Mojardin and Eladio Gaxiola (UAS); and Sergio Knaebel (David and Lucille Packard Foundation). UAS and its faculty oversaw the planning meetings and the workshop (Eladio Gaxiola, Guillermo Rodriguez, Nicolas Castañeda). CESASIN (Luis Miguel Aguiar, Director and Julio Cabanillas) supported planning and execution of the workshop, production of the workshop materials and minutes and provided general coordination. CREDES (Ana Luisa Toscana, Director) provide the workshop venue and other support services. Conservation International (Armando Villalba) also provided support to the workshop. Irma Lorena Camacho Lòpez and Ruth Maria Garduño Gil who volunteered their time to provide oversight of all logistics and arrangements kindly provided additional support. The coordination efforts of the personnel from the Universidad Autonoma de Nayarit are also recognized. The team also wishes to thank the following officials and individuals who participated in the workshop: Gómer Monárrez González (Rector, UAS), Sergio Escutia (President, CESASIN), Ramón Corral (National Fisheries Commission), Enrique Sánchez Cruz (Head, SAGARPA/Sinaloa), Samuel Sánchez Cabrera (Subsecretariat of Fisheries/Government of Sinaloa State), Ricardo Ramírez (President, Municipality of Mazatlán), Lorenzo Gómez Leal (Head, PROFEPA/Sinaloa), Ana Luisa Toscazo (Director, CREDES), Cristina Chávez (Director del CIAD-Mazatlán), Ricardo Romero (consultant, industry representative), Ricardo Urias (Fisheries/SAGARPA), Isidro Osuna Lopez (UAS), Carmen Torres (SEMARNAT). Last but certainly not least, students from Mexico, Nicaragua and the US provided key support to this effort: Luis Alberto Zumaya Tirado and Cinthya Guadalupe Lares Ureta (UAS), Abelardo Rojas Umaña and Candace Martin (UHH).

WATER QUALITY MONITORING AND IDENTIFICATION OF POLLUTION SOURCES LEADING TOWARDS CLASSIFICATION OF BIVALVE GROWING WATERS

Twelfth Work Plan, Aquaculture and Human Health Impacts 1 (12AHH1)
Abstract

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Two major bay systems in Mexico that are the focus of collaborative efforts for international integrated coastal zone management efforts—Bahia Santa Maria (BSM) in Sinaloa and Marismas Nacionales, Nayarit—are also home to growing oyster industries. Oyster farming in Nayarit has a 30-year history, but women's groups in BSM are just beginning. The former has been demonstrated to be a viable alternative to fishing for coastal communities, particularly as women have a high level of participation both in production and processing. Two oyster species are commonly cultivated along the Pacific coastline. *Crassostrea gigas* seed is imported from the US and used for remote cultivation in Mexico, mainly along the northern part of the coast. A native species, *Crassostrea corteziensis*, has sufficiently high levels of localized spat to support a limited industry, mostly confined to Nayarit and two newer farms in Sinaloa. There is also growing interest in other

native bivalve species, so it is hoped that the outcome of this shellfish sanitation improvement effort will have wider benefits.

Among the obstacles to future progress is the question of water quality in bivalve growing areas. Increasing populations and pollution in coastal areas threaten the safety and economic viability of the growing oyster culture industry. Opportunities also exist, as many areas are still relatively pristine and produce a high-quality and safe product. Previous work found that the ability to assure product safety, transport and market in other areas, and produce value-added products could greatly increase the direct socioeconomic benefits this industry provides to coastal communities. There is also a possibility that shellfish could be exported to the US, as two Mexican farms are already doing, if water quality and the regulatory framework are such that growing areas could meet US standards.

Because both the existing Mexican and US protocols and standards would require at least one year of intensive water quality monitoring to classify a growing area, and because these areas are extensive, attempting to classify growing areas is not a trivial task, and resources do not exist to undertake large-scale monitoring efforts. A more feasible option is to conduct rapid assessments that include shoreline surveys and preliminary water quality monitoring to eliminate any areas which could be conclusively barred from consideration and to identify the areas most likely able to meet standards in the future. Once these areas are identified, intensive monitoring efforts could then be conducted in a more cost-effective manner in narrowly targeted geographic areas of the two bays. Participants in this work include: Autónoma de Sinaloa; Pacific Aquaculture and Coastal Resources Center/University of Hawaii, Hilo; University of Hawaii Sea Grant College Program; Ecocostas; Coastal Resources Center, University of Rhode Island; Louisiana State University Sea Grant College Program; CESASIN; CREDES; Autónoma de Nayarit; oyster farming cooperatives of Nayarit; and women's groups of BSM. Investigation 12AHH2 “Outreach and Planning for Implementation of Bivalve Growing Areas Classification and Related Sanitation Action Items,” is complementary to this investigation and constitutes a planning, regulatory, and outreach component.

OUTREACH AND PLANNING FOR IMPLEMENTATION OF BIVALVE GROWING AREAS CLASSIFICATION AND RELATED SANITATION ACTION ITEMS

Twelfth Work Plan, Aquaculture and Human Health Impacts 2 (12AHH2)
Abstract

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Culture of oysters and other bivalve species is a growing opportunity for aquaculture along the Pacific Mexican coast. Bivalve culture and the need for sanitation protocols to assure the safety and quality of the shellfish products are relatively new topics for the Pacific Mexico region. As efforts to diversify aquaculture through the strengthening of shellfish culture are underway, and as consumer awareness of the potential dangers of consuming aquatic products increases, measures to assure the production of safe shellfish and other aquaculture products are needed. This activity is linked to Investigation 12AHH1 “Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters,” and will be aimed at disseminating the findings of that study and raising awareness of the issues associated with shellfish sanitation and other aquaculture products. Researchers, extension agents, and government officials will then work

together to identify strategies and resources to implement recommendations stemming in part from Investigation 12AHH1 as well as the outcomes of the Tenth Work Plan. A wide range of environmental, community, and product sanitation issues were identified during study of finfish, shellfish, and shrimp operations.

Particular attention will be paid to monitoring and classification of shellfish growing waters and actions targeted towards mitigating major sources of pollution that are affecting aquaculture as a whole. Previous work in Bahia Santa Maria (BSM) by the members of the Sinaloa working group has already developed tools and strategies that have led to positive improvements in community sanitation and water quality. Expansion of these efforts within the BSM system and replication in Nayarit would contribute to an increased probability that shellfish growing areas could be classified as approved and that other aquaculture sanitation problems could be addressed.

Specifically, this work will raise awareness among key institutional and community stakeholders about the major issues associated with aquaculture sanitation. Stakeholders will be educated about the technical and legal requirements for safe production of bivalves. Findings, outcomes, lessons learned, and strategies will be disseminated to the authorities and key stakeholders so that joint development of strategies and resources to implement programs for classification of shellfish growing waters and other strategies related to community sanitation and water quality can take place. An implementation plan for the above mentioned topics will also be developed. Participants in this work include: Autónoma de Sinaloa; Pacific Aquaculture and Coastal Resources Center/University of Hawaii, Hilo; University of Hawaii Sea Grant College Program; Ecocostas; Coastal Resources Center/University of Rhode Island; Louisiana State University Sea Grant College Program; CESASIN; CREDES; Autónoma de Nayarit; oyster farming cooperatives of Nayarit; and women's groups of BSM.

FOOD SAFETY AND HANDLING: INCREASING LOCAL CONSUMPTION OF AQUACULTURE PRODUCTS AND IMPROVING QUALITY

Eleventh Work Plan, Disease, Predation Prevention, and Food SAFETY 1 (11DPPR1)
Final Report

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ABSTRACT

This research attempts to elucidate relationships between human health, water resources, and aquaculture status and development in the States of Sinaloa and Nayarit, Pacific Mexico Coast. The focus was on characterizing issues of sanitation, food quality, and safety that affect aquaculture production, economic returns and public health. Three topics were studied: 1) potential oyster growing areas of Bahia Santa Maria (BSM), a major wetlands area of Sinaloa State; 2) shrimp farming areas of BSM; 3) reservoir farming and fishing of finfish; and 4) oyster farming areas of Boca de Camichin, Nayarit. A particular emphasis was put on issues related to bivalve sanitation as culture of introduced and local species of bivalves is growing.

INTRODUCTION

Shrimp aquaculture is a major industry on the coast of Pacific Mexico (Figure 1) and other forms of aquaculture are rapidly growing as shrimp farming suffers major problems such as diseases that

threaten its viability. The collaborating group had worked with coastal stakeholders for at least 8 years to develop Best Management Practices for shrimp farming, but had not focused on food safety and quality issues. Additionally, as interest in other forms of aquaculture grows, attention is needed to ensure that aquaculture products are: 1) safe for local consumption; 2) that measures can be taken to safely handle, process, and transport products; and 3) that market and legal requirements can be met. This is particularly the case for bivalves, which are particularly susceptible to contamination at all phases. Oyster and clam culture is common in Mexico and is growing. New species of bivalves such as pen shells and cockles are being brought into culture. Since most bivalves are consumed raw or lightly marinated in Mexico, appropriate shellfish sanitation is of the utmost importance.

Figure 1: The Gulf of California and the locations of Sonora, Sinaloa and Nayarit States.

Bahia Santa Maria (BSM) encompasses an area of 50,000 ha of wetlands and is surrounded by communities that make their living fishing, farming, and by laboring on large agroindustrial and aquaculture (shrimp) operations. A major city, Culiacan and a number of medium size cities and towns are increasingly encroaching on the agricultural and wetlands areas.

BSM has been the target of national and international conservation and integrated coastal zone management efforts since 1997, primarily catalyzed by the Universidad Autonoma de Sinaloa (UAS) and Conservation International, along with US partners such as the Coastal Resources Center of the University of Rhode Island and more recently, the Pacific Aquaculture and Coastal Resources Center of the University of Hawaii Hilo. These efforts culminated in development of a Bay Management Plan in 2000 and formation of a tri-municipal Conservation and Development Committee legally charged with implementing the management plan in 2004. A number of community-based development efforts were also initiated including community sanitation drives, latrine installation, composting, co-management of the crab fishery, development of sportfishing, use of fisheries products to make fish and shrimp meal, and oyster cultivation.

Learning from the success in BSM, Conservation International then pioneered similar efforts in Marisma Nacionales, State of Nayarit. This area was included in the case studies because it is the principal site of culture for the native oyster species (*Crassostrea corteziensis*). Further, information exchange had taken place between women's groups in BSM, which were beginning oyster culture, and the groups in Nayarit, which were experienced with oyster culture.

At this point, two new perspectives arose among the stakeholder communities and the collaborating group of institutions. First, the potential for alternative forms of aquaculture and mariculture became increasingly attractive as a way to sustainably utilize bay and watershed resources available to the groups. Shrimp farming and other forms of aquaculture were already important in the coastal areas. It was clear however, that major resource, technical, and social challenges existed. Secondly, while previous efforts were largely coastal in their emphasis, the need to work within a watershed context was becoming increasingly clear.

This case study endeavored to achieve the following:

- Identify key issues related to food safety and handling for aquaculture products.
- Identify means by which products can be made more accessible to local and national consumers and in safer forms.
- Identify means by which high value, locally produced aquaculture products can be exported to US or other international markets to increase economic benefits, particularly in the case of products produced by cooperatives.
- Develop protocols to increase safe-handling practices for the major aquaculture products at all phases from stocking to consumption.
- As a sub-component, study shellfish sanitation issues that affect the safety of locally produced bivalves and prevent exportation of high value species and develop an action strategy that identifies steps required to improve both.
- Identify next steps and make recommendations for future work.

MATERIALS AND METHODS

Case study research began in March 2004 with a joint meeting of the Collaborative Group in Culiacán, Mexico at the Autonomous University of Sinaloa. The principal Mexican public institutions involved in this work are the Universidad Autonoma de Sinaloa (UAS), Comite Estatal de Sanidad de Sinaloa (CESASIN), Centro de Investigacion Alimentaria y Desarrollo/Mazatlan (CIAD), Universidad Autonoma de Nayarit, Conservation Internacional. US universities involved in this work include the Pacific Aquaculture and Coastal Resources Center/University of Hawaii-Hilo (PACRC/UHH), Coastal Resources Center/University of Rhode Island (CRC/URI), Louisiana State University Sea Grant Program (LSU), and the University of Hawaii Sea Grant College Program.

The research involved close coordination with social and private sector stakeholders that were engaged in aquaculture, were planning on starting aquaculture projects, or community groups working on other forms of alternative livelihoods. Most of these groups had long-standing ties with the collaborating group vis-à-vis the long-term conservation and management efforts. Twenty-one principal researchers from Mexico, Ecuador and the US conducted research as the basis of the case studies including specialists in: biology, aquaculture; aquatic pathology; fisheries; nutrition; public health; architecture; coastal management; community, urban and regional planning; gender; conservation; economics; sociology; and political science. Six students were also involved in the research with two of them incorporating research findings into their theses. Research was conducted through literature review, site visits and observations, and stakeholder interviews over a period of 14 months. Most of the site visits included a component of training or outreach in topics related to aquaculture development, management or health issues, including shellfish sanitation. The collaborating group met on a regular basis to share findings, mutually review and critique materials, and to draft the final document in late 2005.
The research sites were chosen based on three criteria:

- The presence of communities that had been involved in long-term conservation and management efforts that included some aspect of aquaculture and/or fisheries.
- The site has economic, social and conservation significance to the region.
- The site exemplifies issues related to aquaculture development in the region.

Site Descriptions
1. Bahía Santa María
The State of Sinloa is the site of important fisheries and aquaculture activities being the largest producer of fisheries products in terms of revenue, the second in volume, and the major site of shrimp farming. It possesses numerous bays, coastal lagoons, rivers, and dams. The State has 656 km of coast line with 221,600 ha of coastal lagoons. Bahia Santa Maria (Figure 2) is the largest bay

in the State having 50,000 ha of wetland area. It is connected to the Gulf of California by two mouths.

Figure 2. Location of Santa Maria Bay within the State of Sinaloa and the structure of the Bay including its two component lagoons, Playa Colorada and La Reforma.

BSM encompasses two major coastal lagoons, Playa Colorado (6,000 ha) to the north and Santa Maria-La Reforma (47,000 ha) to the south, 153 islands, 25 estuaries, and 3 bays (Figure 2). The fisheries resources of the bay are rich and include snapper, bass, snook, mullet, and other species. Shrimp, which is fished for 6 months annually, is the principal fisheries resource, and crab is also important.

The freshwater for the system comes from diverse sources including the Mocosito River, which is 19.1 km in length. The abundant freshwater is the basis of agriculture, the principal activity of most of the communities, which rely seasonal and irrigated forms of agriculture. River fisheries are the principal resource for five communities on the lower watershed. There are 88 shrimp farms totaling 9000 ha found in the brackish water areas behind the mangrove zone.

2. Eustaquio Buelna Reservoir

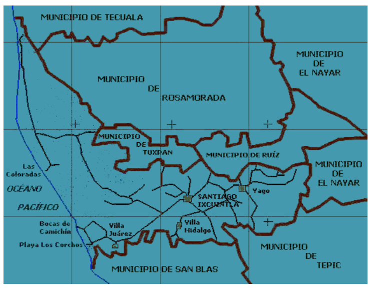
The Mocorito River is a major source of freshwater for Santa Maria Bay and flows directly into Playa Colorada Bay. Much of the water produced (158 Mm^3 annually) in this the watershed is captured by the Estaquio Buelna Reservoir, which became effective in 1981 (Figure 3). The watershed includes many of the major growing cities and towns in Sinaloa. The reservoir has a capacity of 343.8 million Mm^3 and annually supplies 104.8 Mm^3, mostly for irrigation and cattle production. The reservoir is critical to the State, providing hydroelectric power, irrigation, sportfishing, commercial fishing, and recreation. It was chosen as a representative study site for the 5 similar reservoirs in the Sinaloa. The reservoir is stocked with catfish, tilapia, and bass. The fishing cooperatives harvest the fish and have made efforts to begin aquaculture in pens as is done in other reservoirs. The reservoir fishing and aquaculture throughout the state is facing increasing problems with decreasing water volume, fish sizes, and fish abundance.

Figure 3. Fishing and fish culture in Eustaquio Buelna Reservoir.

3. Boca de Camichín

The areas known as Marismas Nacionales (National Marshes) where Boca de Camichin is located, is situated in the State of Nayarit. This physically complex wetlands area has a surface area of 200,000 ha and constitutes an important area of wetlands, lagoons, and mangroves. Approximately 15% of the mangroves and 20% of the estuarine area of the nation is found in here. The area is also home to four major indigenous groups. Boca de Camichin is located in the mouth of the San Pedro River.

Figure 4. Location and aerial photograph of Boca de Camichín.



Local communities primarily dedicated to river fisheries have been cultivating a native species of oyster (*Crassostrea corteziensis*) for 35 years using floating rafts. The culture area covers 300 ha with 1,200 rafts, involves 800 people, and generates an estimated $15,000,000.00 pesos annually.

Figure 5. Oyster culture at Boca de Camichín.

RESULTS

Oyster culture growing areas

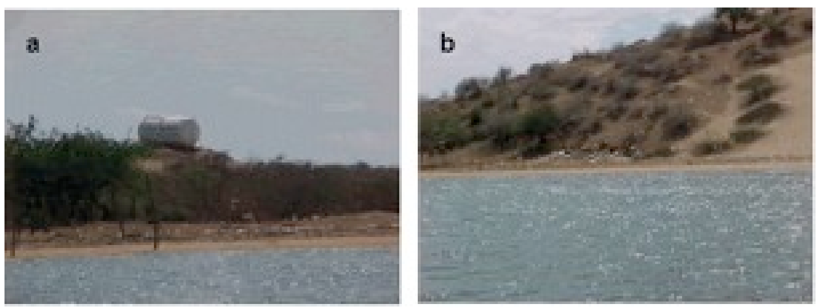
Bahia Santa Maria

In Bahia Santa Maria several communities wish to begin or reinitiate oyster culture. In the 1990's *Crassostrea gigas* was cultured with some success in the area. Currently a women's cooperative in Playa Colorada is mounting a bivalve culture project. A shoreline survey was conducted in two areas, "Region of the Whale" close to the mouth of the estuary and at "Perihuete" located closer to the community to locate sites for the native oyster, *Crassostrea corteziensis*, which is observed to set in abundance on mangroves in the area.

The shoreline survey revealed that there was no apparent influence of agriculture, drains, industry, or human settlements. Potential problems were detected near Perihuete where one beach had large quantities of waste left by seasonal tourists that camp in the area (Figure 6). There are no provisions made at this popular beach for garbage disposal, latrines, or other precautions. The other potential site "Region of Whales" was apparently free of point sources of contamination, but is located far enough from the community that logistics and costs could affect production. Bird nesting sites, common in these coastal areas and a major focus for conservation efforts, may contaminate these sites with their waste. Ironically, effects of ecotourism and conservation may produce conflicts with aquaculture.

Non-point source pollution was more difficult to evaluate. It is known that most communities around BSM have sanitation issues for solid wastes and sewage, but many have engaged in community clean-ups and latrine projects. The upper watershed is clearly a potential source of contamination from agricultural and industrial sources of contamination (see Case Study #1), but inadequate data for the area exists. In general, any project involving production of safe shellfish will have to expend considerable effort and resources in selecting acceptable growing areas since no shellfish sanitation programs exist in Sinaloa, although policy and regulatory frameworks are adequate and provide a good starting point.

Figure 6a and 6b. Beach at “El Perihuete”, at Bahía Playa Colorada contaminated with solid wastes from tourists.



Oyster culture in Boca de Camichin

Oyster culture of *C. corteziensis* began in Nayarit in 1976 by a group of river fishers and is considered one of the success stories of aquaculture in Mexico. Oysters are cultured by 800 people on rafts using spat sourced from spat collectors. Women are involved in the production, but dominate the marketing and processing of the oysters. Local attempts to produce value-added products such as pates and escabeche are beginning to have success. The annual value of the oysters is estimated at $15,000,000.00 pesos. The people also work at fishing, shellfish collection, and shrimp capture. They credit the oyster farms with the relatively good infrastructure and services available in the community.

When harvested, the oysters are transported in bushel bags or trays to nearby areas and are maintained in the shade for up to three days. Refrigerated trucks are used to transport oysters longer distances. Ninety percent of the harvest is transported outside of the immediate area. Generally, the area is known for providing safe, high quality oysters. While sanitary conditions are probably better than in many areas, room for improvement exists. The oyster growing area of Boca de Camichin is a narrow channel surrounded by residences; the safety of their waste systems is unknown. There are little sanitary controls imposed on post-harvest handling, vending, or transport. Particularly now that the women are bottling and processing oysters into products such as pates, training in food handling and preservation is urgently needed as oysters are a low acid food susceptible to dangerous forms of contamination including botulism.

Water quality is also threatened by discharges into the San Pedro River from the cities of Tuxpan and Mexcaltitlan. Agriculture also contributes to poor water quality in the vicinity. Tourists also visit the area and use coastal areas, particularly during Easter Week, when seafood consumption also peaks, and represent potential sources of contamination, as most tourist beaches do not have sanitary facilities or adequate solid waste disposal. The area is also highly vulnerable to floods and hurricanes, which could contaminate growing areas.

For all shellfish growing areas in Mexico, water quality deterioration produced by other activities and the surrounding human populations constitutes a serious threat to shellfish sanitation. There are few shellfish growing areas with water quality monitoring or where shoreline surveys have been conducted. Producers and handlers have little awareness of sanitation issues or measures. There is anecdotal evidence that the incidence of gastrointestinal illnesses is on the rise and that

some consumers are declining to eat shellfish due to concerns about product safety. This threat is particularly acute for a population which suffers from high rates of diseases that affect the immune system.

Shrimp farming in BSM

BSM is the site of 88 shrimp farms that operate for two cycles per year. Three major processing plants are located there and the bulk of the product is exported to the US. The characteristics of these ponds are well known, having been the subject of several assessment efforts. Most use improved methods and biosecurity measures. Some do not have electricity, potable water, telephones, or drains. Nearly all farms are susceptible to flooding due to the lack of drainage. Variation in physio-chemical parameters caused by climatic events contributes to stress levels often provoking shrimp mortalities. Agriculture and industry in the upper watershed release pesticides and heavy metals thought to exacerbate these problems.

This research suggests that in general, most of the farms generally employ good management practices intended to protect the shrimp and minimize environmental impacts. Most farms have containment systems for fuel tanks. Among the few problems encountered were the use of antibiotics, fertilizers, immuno-stimulants and other chemicals. Some farms do not use sufficient ice during harvests and others do not have potable water. Guard dogs could contaminate ponds. Some farms do not impose controls on personnel hygiene and lack adequate sanitary facilities. The main reasons farmers do not adopt stricter measures are: 1) lack of awareness of sanitation principles and protocols, 2) lack of requirements to improve conditions, and 3) economic issues.

Most water discharge is done without treatment, although water may be recycled through canals or natural lagoons. However, this may not be effective due to the rates of exchange. None of the farms shared water quality measurements of their effluents or source waters despite requests from researchers. Some studies have shown significant levels of eutrophication in the bay, which is attributed to: 1) discharges from urban areas, 2) domestic or industrial discharges, 3) nutrient discharges from shrimp ponds, and 4) a low rate of water exchange in the estuary. Red tides occasionally appear although no reports of massive mortalities exist.

Sanitation programs focusing on post-harvest issues have played an important role in the generally good status of the shrimp culture industry in this region. Producers are generally aware of the relationship between public health and product safety, as well as the market ramifications.

Freshwater fish culture

A variety of freshwater fishes are cultivated including tilapia, bass, catfish, and native species of cichlids. The eleven major reservoirs in Sinaloa represent important commercial fishing, sportfishing, and fish culture sites, but the priorities for water allocations are agriculture, domestic, and industry. The Eustaquio Buelna Reservoir in the Mocorito River is typical of these reservoirs. Aquaculturists and fishers in this area are organized into three cooperatives and have operated since the reservoir opened. There are 309 fishers, 46 boats, and 231 fishing gears. Tilapia culture was started with fingerlings from the Aquaculture Center, "El Varejonal". Tilapia are harvested from June to August. This is extensive culture, although there is interest in moving towards improved forms. There is no water quality data for the reservoir, but the research team observed multiple sources of potential contamination when studying the watershed area. A major problem is drying of the reservoir as aquaculture does not have a water allocation and the region has been suffering from drought for several years.

Most of the tilapia production is consumed locally or transported to Guadalajara in trucks with ice (Figure 7). The tilapia is filleted or whole, catfish is sold whole, and price is set according to size and quality. Most tilapia is captured at a small size. Fishers report that size has been decreasing; they believe this is due to inbreeding since re-stocking rarely occurs.

Figure 7. Selling and transporting tilapia.

Generally sanitation protocols have only limited application at the reservoir fisheries. Only rustic, open air facilities exist for processing. These do not have refrigeration, potable water, and often lack ice. No sanitary facilities for the workers are present. Abundant amounts of animal waste were observed. Waterfowl nest and rest on the shore near the processing area. This typical of the reservoir areas.

Gnathostomosis

Another serious, emergent problem with freshwater aquaculture are nematodes of the genus *Gnathosoma*, which cause Gnathostomosis when ingested by humans, most commonly in raw or undercooked meat or fish. This produces dermatological, ocular, intestinal, and neurological symptoms and can be fatal. The syndrome appears to be increasing in frequency in Sinaloa. Local traditions of consuming raw fish and the export of this fish to other areas of Mexico have the potential for creating a serious national health problem unless steps are taken.

DISCUSSION

Human health is clearly impacted by the general deterioration of water quality in the region and lack of awareness of sanitation requirements. Mexico has adequate policy and regulatory protection, but implementation and enforcement are the issues in the case of contamination by industrial, urban, and agricultural sources. The poorer coastal communities and largely rural municipalities are often prevented from taking measures recognized as necessary simply due to a lack of resources.

Poor water quality is a serious concern as aquaculture grows and interest in brackish water and freshwater alternatives to shrimp farming increases. Particularly for bivalves grown in coastal areas, careful attention needs to be paid to selecting culture areas that are clean enough to produce safe, high quality shellfish. Although Mexico has adequate regulation and policy for shellfish sanitation which is analogous to that of the US, implementation and capacity to classify and monitor shellfish growing areas is lacking. This will be the focus of the Year 12 ACRSP Human Health and Aquaculture Work Plan. As shellfish farming becomes a viable economic alternative in more coastal areas, such as what has happened in Nayarit, measures need to be taken to protect what is expected to be a rather limited range of areas suitable for shellfish culture as coastal urbanization, agricultural, and industrial activities continue to develop in Pacific Mexico.

A great deal of work is also needed in the area of awareness-raising and skill building in product quality, safety and sanitation to protect human health, but also to improve the quality and shelf-life of products and to extend the range of marketing possibilities beyond the immediate vicinity of the

farm. All efforts to improve the situation require better delivery of extension services, another aspect of the Human Health and Aquaculture project. A major lesson learned is that successful community development, aquaculture, and health projects have relied on extension services, usually provided by multiple partners. If the extension methods and approaches applied during past work by the collaborating group are applied to aquaculture and human health efforts, it will greatly improve their chances of success.

CONCLUSIONS

Human health, aquaculture, and environmental quality are inextricably linked. Aquaculture offers much potential to improve food security, revenues, employment opportunities, and potentially offers alternatives to fishing and other extractive activities. It may even offer some individuals the opportunity to remain in their coastal villages by reducing the attraction of emigration or involvement in the drug trade. Successful aquaculture development beyond current levels will require careful attention to understanding and maintaining water quality, positioning aquaculture as deserving of water allocations, integrating development efforts into wider community development and watershed management efforts, and integration of stakeholders and institutions not commonly involved in this field. Developing a system of implementing and enforcing shellfish sanitation measures is critical, as is improved delivery from multi-institutional extension services.

ANTICIPATED BENEFITS

Quantitative and qualitative benefits include:

- Improved understanding and data available for key technical issues related to human health, aquaculture and fisheries detailed in a 150-page book.
- 75 professionals trained in advanced extension methods and aquaculture skills.
- Leaders and members from 5 communities participated in the training.
- 22 institutions participated in the workshops.
- Training materials from the workshop have subsequently been used in three other ACRSP/SUCCESS sites (Nicaragua, Ecuador, and Tanzania).
- Of particular note is that 8 members of CESASIN, the primary aquaculture extension institution in the region, received further training.
- CESASIN has decided to expand its extension coverage to the shellfish sector.
- Professionals in other sectors were made aware of the benefits of aquaculture for rural communities and the benefits to health.
- Issues related to human health and aquaculture were identified and characterized; this information was incorporated into the associated case studies.
- A gender balance was achieved with 45% of the participants being women.
- Connections between researchers and extension workers were strengthened or established.
- Extension training materials in Spanish were produced, distributed and made widely available.
- Results and skills stemming from this workshop greatly enhanced the human health case studies and two ACRSP investigations.
- Four students from UAS participated in this work directly and two students from UHH contributed to planning and preparation.

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