AQUAFISH CRSP

TECHNICAL REPORTS
INVESTIGATIONS 2009–2011
VOLUME 2

AUGUST 2012

Aquaculture & Fisheries
Collaborative Research Support Program
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AQUAFISH CRSP TECHNICAL REPORTS: INVESTIGATIONS 2009–2011, VOLUME 2

Program activities are funded by Cooperative Agreement No. EPP-A-00-06-00012-00 from the United States Agency for International Development (USAID), and by participating US and Host Country institutions.

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Cover Photo

Buyers haul off a basket of freshly caught fish from Tri An Reservoir in Vietnam, where AquaFish CRSP researchers are assessing the impacts of fish stocking on wild fish populations. Photo by Peg Herring, Extension & Experiment Station Communications, Oregon State University.

This publication may be cited as:
AquaFish Collaborative Research Support Program. August 2012. Technical Reports 2009–2011, Volume 2. AquaFish CRSP, Oregon State University, Corvallis, Oregon, 414 pp.

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Table of Contents: Volume 2

Food Safety & Value-Added Product Development

Maximizing the Utilization of Low Value or Small-Size Fish for Human Consumption by Improving Food Safety and Value Added Product Development (Fermented Fish Paste) through the Promotion of Women's Fish Processing Groups/Associations in Cambodia (09FSV01UC) 1

Demonstration of Sustainable Seaweed Culture, Processing and Utilization in Aceh, Indonesia and the Philippines – Opportunities for Women to Improve Household Welfare (09FSV02NC) 39

Assessing the Impacts of Sustainable Freshwater Aquaculture and Small-Sized/Low-Value Fisheries Management in the Lower Mekong Basin Region of Cambodia and Vietnam (09FSV03UC) 46

Technology Adoption & Policy Development

Aquaculture & Fisheries CRSP Sponsorship of the Ninth International Symposium on Tilapia in Aquaculture to Be Held in Shanghai, China (09TAP01UA) 86

Internet-Based Podcasting: Extension Modules for Farming Tilapia in the Philippines (09TAP02NC) 90

Development of Alternatives to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin of Cambodia and Vietnam (09TAP03UC) 96

Harnessing the Opportunities and Overcoming Constraints to Widespread Adoption of Cage Aquaculture in Ghana (09TAP04PU) 105

Assessment of AquaFish CRSP Technology Adoption and Impact (09TAP05OR) 115

Project Planning Meeting on AquaFish Technology Discovery and Impact Assessment (09TAP06OR) 144

Effects of ACRSP and AquaFish CRSP Initiatives and Activities on Aquaculture Development in Kenya (09TAP07PU) 149

Training Trainers for Long Term and Sustained Impact of Pond Aquaculture in Africa (09TAP08AU) 159

Marketing, Economic Risk Assessment & Trade

Market Assessment and Profitability Analysis of Aquaculture Enterprises in Uganda (09MER01AU) 160

Value Chain Development for Tilapia and Catfish Products: Opportunities for Women Participation (09MER02PU) 164

Improving Supply Chain Opportunities for Tilapia in the Philippines (09MER03NC) 180

Value Chain Analysis of Snakehead Fish in the Lower Mekong Basin of Cambodia and Vietnam (09MER04UC) 195

Watershed & Integrated Coastal Zone Management

Effects of Watershed-Water Quality-Aquaculture Interactions on Quantity and Quality of Water from Small Catchments in South Africa and Uganda (09WIZ01AU) 243

Surface Catchment Development and Sustainability Evaluation for Multipurpose Water Supply for Meeting Aquaculture and Other Water Needs (09WIZ02AU) 252

Improved Cages for Fish Culture Commercialization in Deep Water Lakes (09WIZ03UM) 260

Mitigating Negative Environmental Impacts

Invasion of the Red Swamp Crayfish (*Procambarus clarkii*) in China: Genetic Analysis of the Invasion and the Impacts Evaluation (09MNE01UM) 277

Ration Reduction, Integrated Multitrophic Aquaculture (Milkfish-Seaweed-Sea cucumber) and Value-Added Products to Improve Incomes and Reduce the Ecological Footprint of Milkfish Culture in the Philippines (09MNE02NC) 320

Integrating Environmental Impacts, Productivity, and Profitability of Shrimp Aquaculture at the Farm-Scale as Means to Support Good Aquaculture Practices and Eco-Certification (09MNE03UM) 336

Developing Management Recommendations for Freshwater Small-Sized/Low Value Fish in the Lower Mekong Region of Cambodia and Vietnam (09MNE04UC) 359

The Impact of Fish Stocking on Wild Fish Populations, Fish Production and Aquatic Environment in Irrigation Reservoirs in South Vietnam (09MNE05UM) 375

Evaluating the Relationship Between Semi-Intensive Aquaculture and Natural Biodiversity (09MNE06UM) 402

Reaching the Farms Through AquaFish CRSP Technology Transfer: Elimination of MT from Intensive Masculinization Systems Using Bacterial Degradation (09MNE07UA) 409

Maximizing the Utilization of Low Value or Small-Size Fish for Human Consumption by Improving Food Safety and Value Added Product Development (Fermented Fish Paste) Through the Promotion of Women's Fish Processing Groups/Associations in Cambodia

Food Safety and Value-Added Product Development/Study/09FSV01UC

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ABSTRACT

The fisheries resources in the Cambodia are faced with drastic decline due to the rapid increase in population and illegal fishing activities; many captured fisheries resources have been largely overexploited, as well as the increasing competition and conflict between the use of low value/trash fish for feeding and human consumption; and most traditional fisheries production is more focused on fermented fish paste that is very commonly consumed especially by the rural/very poor people.

The project entitled "Maximizing the Utilization of Low Values or Small-Size Fish for Human Consumption through Improving Food Safety and Value Added Product Development: Fermented Fish Paste/*PRAHOC* through the Promotion of Fish Processing Women Group/Association in Cambodia" is aimed at improving the Cambodian's food safety, profitability in competitive market with other international neighboring countries, and maintaining our fermented fish paste/*PRAHOC* brand name, its value and its marketing. This project also helps support the Cambodian women that are involved in the processing chain from farm to table - it means that everyone from processors to traders, consumers, competent authority they can perform their functions effectively. So they really play very important roles and can generate their income from this by applying standards and codes of practice that can lead the women towards having a voice, which is traditionally limited in the Cambodian culture.

However, the effectiveness and efficiency of this project also relies on the help of government and private producers, NGOs, researchers, policy makers, and other involved stakeholders who can perform their roles well together in order to improve and ensure fish and fisheries/food quality, hygienic food safety in Cambodia for all consumers. But in this project, we do not have enough time to ensure the effectiveness and efficiency of our Fermented Fish Paste/*PRAHOC* Technology Development, GMP/GHP Code of Practice and Product Standard Development in conducting trials or experiments, and involving, throughout this fermented fish paste processing, the women groups and finalizing these standards and practice codes on the national level. As we already know, Cambodians already have their set ways of producing so it is difficult for us to apply and disseminate all of this information, to educate and to communicate to them with the utmost impact over a short duration. But if our government and policy-makers can give more priority to improving, ensuring and mandating food safety standards together with the private sector and other public sectors with some financial and technical support too. Then, maybe, we can achieve it in a very short time.

INTRODUCTION

1. In Cambodia, low value/trash fish is used for human consumption, particularly by the poor as it is relatively cheap and provides good sources of protein and other nutrients to humans, especially pregnant women and children. The fish is utilized for household food security and income. Artisanal processing is undertaken to make fermented fish or fish paste (*PRAHOC* in the Khmer language) or processed in other ways (e.g. fish sauce, *teuk trei* in the Khmer language) using different traditional processing practices. This processing is done primarily by women. This processed product is used in the household and sold in local and regional markets (Thailand, Laos, and Vietnam) and provides income to the household. Tens of thousands of the Cambodia poor, especially rice farmers, who are living hundreds of kilometers away from the main natural freshwater water bodies, come to the *Tonle Sap* River during December to February every year to buy low value or small-sized fish to make *PRAHOC*. Vietnamese traders are known to come to Cambodia to purchase both fresh and semi-processed low value/trash fish for further value-added processing in Vietnam. The increasing competition for low value/trash fish for aquaculture has reduced the supply of fish for these value-added products. *PRAHOC* is produced in a variety of ways depending on the raw material, but there are two main types: boneless and bony. Boneless *PRAHOC* is made almost exclusively from *gourami* species and commands a high price in the restaurant trade, for export and amongst higher income consumers. *PRAHOC* made from small mixed species is less valuable but is a more universally made product from the messes of small fish caught in the *dai* fisheries or from other miscellaneous fish caught at other times of the year. It is produced essentially by taking fresh fish and removing the heads and scales and intestines. The fish are salted and dried for a few days before being mixed with salt and stored in airtight ceramic vats to mature. The products are made by subsistence fishermen and others when fish are abundant as a means of storage for later consumption or as a product for sale or barter for other food stuffs.

2. *PRAHOC* is perhaps the most widely consumed fish paste, but the quality of this product varies and has a short shelf-life with a number of health concerns associated with this. Due to lack of standards for most of the products and lack of inspections and controls, there is significant value loss. There are no official control services available at central level and in provinces for products intended for domestic consumption, consequent to which, health control and monitoring of production conditions are not in place at any stage of the fish production chain. The official laboratories are not in a position to perform the range of analysis required for quality checks. Health conditions during production and storage of fishery products are not in line with the requirements and fish-borne illnesses are recognized as an important public health problem. So far, there are few regulations and standards related to fish and fish products. The shortage of standards addressing fish, food additives and fish-feed hinders action against adulterated or contaminated food. Overcoming this would be important for achieving the goal of protecting the people against fish borne diseases (UNDSF-8; NSDP-4.45/4).

3. According to the results of gender implications in the study conducted by the CBCRM Learning Center in Cambodia, "The Role, Needs, and Aspiration of Women in the Community Fisheries in Cambodia", in six fishing communities: "the main roles of women in fisheries-related livelihood activities, the results from most of the case studies are consistent with the general understanding from the literature review. This is that women are engaged in a variety of fisheries-related livelihood activities on their own small-scale capture fisheries, gathering of aquatic plants and animals, aquaculture - and also play a supportive role in the fishing activities of their husbands. But the main responsibility of women in fisheries-related livelihoods is in the post-harvest sector, including processing and trading fish." (Keang Seng 2001; Khim et al. 2002; IFM 2007). In all study sites, women are viewed as more competent than men in marketing fish and take more responsibility in the post-harvest stage of fisheries livelihoods. In some cases, men immediately

sell the fish to collectors at landing sites. Women think of this as a disadvantage because men do not usually negotiate prices or look for the best buyer and thus may not get a good price for their catch. Women's roles in fisheries are often invisible because fisheries management normally focuses only until catch and does not take the post-harvest stage into consideration. It is noted that women play a large role in the post-harvest stage, and it would not be an exaggeration to say that the need created in the post-harvest stage is largely determined by the effort for catch. Many studies described women's roles in every aspect of rural livelihoods in Cambodia, including some documentation on the traditional division of labor between men and women in agriculture. However, there has been little examination on women's roles and contribution to fisheries post-harvest sector. Understanding gender in the development of fisheries post-harvest is very important especially for their participation and contribution to improve their livelihood and food quality, safety, and food nutrition in order for the sustainable development and management of fisheries natural resources. It can also help to improve women's rights and participation in the socio-economic activities. The results of work undertaken in Phase-I (*Implementation Plan 2007–2009*) show that hygienic and quality of *PRAHOC* are the main driven factors for local and external demands. The study also showed that semi-processed products of small-size fish are also important for external markets (e.g. Thailand and Vietnam). So hygienic and quality issues should be addressed in the second phase of the project. The study of Phase-I also documented traditional and modern *PRAHOC* processing technologies, and compared the two in order to develop Best Practices for producing *PRAHOC*. For phase-II (*Implementation Plan 2009–2011)*, we will use this output on best practice for *PRAHOC* processing method to develop the *PRAHOC* quality and safety guidelines, standardized packaging and labeling for fish paste and apply to promote the women fish processing group/association. So based on this investigation we hope that we will have a direct and indirect effect/impact to the National Fisheries Post-Harvest Sector. The results can be used to effectively enhance human health to all consumers and processors of the fish paste in order to promote the alternative livelihood/employment of the people who depend on the fisheries, especially women in the community fisheries members/fishers/processors in order to increase their income. These activities will also help to improve women's sharing of the added value and improve the social/family economic livelihoods, and equal rights in family decision-making as many of Cambodian women have low education.

METHODOLOGY

This investigation is a study which was comprised of the following activities:

- **The Literature review of the result** from first phase with a desktop survey to better understand fermented fish paste processing practices in Cambodia and fermented fish processing quality standard guidelines and also review of the international standard from *Codex Alimentarius* in order to standardize the code of practice/guidelines to approve not only for national use but also for international acceptance;

- **Field observation, focus group discussion, and key informant interview observation** using some guide questions to the processors to study processing practices on the processing plant/chain and areas of fermented fish paste product and to identify problems and issues related to food safety, processing, and value-added product development.

- **Identify and analyze the composition and natural and chemical hazard of the products** by getting samples from the site and then sending to the accreditation laboratory to check and analyze it. As we already know, *PRAHOC* is very uniqueness and traditional fisheries product and food for Cambodian people and some Asian people like very much to consume it and no international standard or guideline/GMP/GHP code of practice has been done or developed yet. So all the parameters are the basic criteria that we need to develop and identified by our self for the product standard and in order to identify an effectiveness of this product standard we need to test and analyze all of these parameters. So these result of these samples we can limit the amount of every parameters that should have how much amount as minimum and maximum in the product standard and for some parameters that not include in the testing and analyzing, we just are adopted from the international *Codex Alimentarius* that they already internationalize used it.

There has been testing and analysis of all parameters of all the composition and natural and chemical hazard of the *PRAHOC* products (Appendix I). Four samples (one each from small scale, medium scale, and large scale producers, and public markets with two types of *Prahoc* (boney and boneless) from nine provinces (Kampong Chnnang, Pursat, Battambang, Siem Reap, Kampong Thom, Kampong Cham, Kraties, Kampong Som, Takeo, Kandal) and five samples from public markets and department store in Phnom Penh. Testing and analysis were done for original baseline before applying the *PRAHOC* best practice GMP/GHP code of practices and product standard draft and the second testing was after applying the *PRAHOC* best practice for GMP/GHP code of practice and product standard to the trial women groups in Siem Reap Province and some family processors. This was done through a consultation workshop process of this standard development and awareness building and by mass media (TV, Radio, and FiA magazine) to all the same parameters, samples size, and samples locations.

- Conducted many consultation workshop/meetings with processors, who are primarily women, and representatives from Department of Fisheries Post-Harvest Technology and Quality, Department of Aquaculture Development, Department of Fisheries Administration and Litigation of Fisheries Administration (FiA); other relevant agencies involving in food safety and legal framework such as Department of Agriculture Legislation, Department of Agriculture Industry of Ministry of Agriculture, Forestry, and Fisheries (MAFF); Department of Food and Drug, and Department of Legislation of Ministry of Health (MoH); Department of CAMCONTROL of Ministry of Commerce (MOC); Department of Legislation and Institute of Standard of Cambodia (ISC) of Ministry of Industry, Mine, and Energy (MIME), on the best practice of fermented fish paste product quality standard and safety guideline, packaging and labeling. (Refers to the Photo 14, 15 &16).

- Quality method will be employed in analyzing data and developing the guidelines, standardized packaging and labeling of *PRAHOC* product that will assist with analyses by Dr. Chong Lee, a Food Scientist of the University of Rhode Island, USA and some expert from FAO, Rome, Italy too.

- Outreach to promote the women fermented fish paste processing group/association and apply the best practice quality safety guidelines, standardized packaging and labeling to improve the product quality, safety, values added, and competitive market to women processors.

- Publishing and disseminating the best practices for quality and safety guidelines, packaging, and labeling standards of the fermented fish paste product to processors and provincial fisheries officers through research reports or guideline book, newspaper/ magazine article, TV/radio. The publications (Appendices II and III) will be translated into the local Khmer language.

RESULTS

The main objective of the investigation is to work with women to improve and ensure food safety and values added of fermented fish paste product for local consumers and the competitive markets in

Cambodia, and the development of women fish processing group/association through the development, application and dissemination for national use and involving other stakeholders in the processing chain of the Product Technology Development, GMP/GHP Code of Practice and Product Standard Development from the result of the project study. The Investigation IV (09FSV01UC) was implemented and achieved the following results:

1. **Institutional Capacity Building:**
   - ✓ Developed a finalized set of the fermented fish paste guideline and standard on the Product Technology Development, Good Manufacturing Practice (GMP) and Good Hygienic Practice (GHP) Code of Practice and Product Standard Development for generalize use at the national level through many consultation workshops, meetings with the fermented processors, traders, fisheries authorities, standard developer from the Institute of Standard of Cambodia (ISC) of Ministry of Industry, Mine and Energy (MIME) and some experts such as Dr. Chong Lee, a Food Scientist of the University of Rhode Island, USA and many more from the FAO in Rome, Italy with other relevant agencies such as Ministries of Agriculture, Department of Food and Drug of Ministry of Health (MOH), Directorate Department of CAMCONTROL of Ministry of Commerce (MOC).

   - ✓ Developed a trial women processor group/association in *Siem Reap* province in order to improve and enhance the fermented fish paste product with the new finalized draft development of the best Product Technology Development, GMP/GHP Code of Practice, and Product Standard Development in consultation with and guide of many stakeholders and experts.

   - ✓ Conducted two trainings to build the capacity of the Research Team Members and the Fisheries Officers from the Central and Provincial of Fisheries Administration together with the Fermented Fish Processors on the General GMP/GHP Code of Practice for fish and fisheries products as a basic concept to improve and ensure the fish and fisheries products quality, safety and values added in Cambodia.

2. **Awareness Raising and Standard/Code of Practice/Guideline Transfer:**
   a. **Awareness Raising:** carried out public awareness activities in the form of Inception Workshop, Consultation Workshop, and Dissemination Workshop/ training, and Information Education and Communication (IEC) materials and disseminate all activities of the project through the National Mass media (TV and Ratio) and also the National Fisheries Administration and Ministry of Agriculture Forestry and Fisheries Magazines too.

      - **Inception Workshop:** Introduced this Project Investigation IV within the Inception Workshop of the whole AquaFish CRSP Project activities at IFReDI to provide awareness with more than 40 participants of both national and provincial government fisheries officers, NGOs representatives, local communities, and other relevant stakeholders participated. The workshop aimed to provide awareness and hold consultation among the participants, particularly the stakeholders whose work related to aquaculture and post-harvest fisheries quality and safety development sector as well as to receive their suggestions and recommendations.

      - **Consultation Workshop:** Conducted the workshop and meeting to consult with the fermented processors, traders, fisheries officers, local authorities, other relevant agencies involved in the food quality and safety such as from the department of agriculture industry, department of agriculture legislation, and other representative of Ministry of Agriculture Forestry and Fisheries; Institute of Standard of Cambodia (ISC) of Ministry of Industry, Mine, and Energy (MIME); Directorate Department of CAMCONTROL of Ministry of Commerce (MOC); Department of Food and Drug of Ministry of Health (MOH), and other national and international experts with the workshop aim being to conduct awareness and consultation on the Fermented Fish Paste (PRAHOC) Technology Development, GMP/GHP Code of Practice, and Product Standard Development and disseminate through national TV, radio, and magazines.

- **Dissemination Workshop:** Organized the workshop to disseminate the research results of Investigation IV to about 100 participants - processors, traders, local authorities, Central and Provincial Fisheries Officers, researchers, NGOs, and other relevant agencies involved in food quality and safety, and representatives from local community fisheries in all the provinces in Cambodia. The workshop provided awareness-raising on the important role of fermented fish paste/*PRAHOC* quality, hygienic and safety and values added for promoting market of this product, that every Cambodian people and any other neighbor people that also consume this kind of fermented fish paste as a ingredient and food for every days in daily protein intake of local people.

- **Impact Observation on Fermented Fish Paste/*PRAHOC*:** After two years with the project, we can now see the Cambodian people, and not only the *PRAHOC* processors and traders and consumers, also start to care about the food quality, hygienic and safety of their product. Even those from the fisheries administration and Ministry of Agriculture management level also better understand and consider more, compared to before this project implementation when the only concern was about the basic need to fill stomachs and not about food quality, hygienic, and safety. And for some time even the women processing group was already applying and trying these best standards and codes of practice before the finalized draft was submitted to the Ministry of Agriculture Forestry and Fisheries and Institute of Standard of Cambodia for their approval and acceptance as the national standard after the trial of this pilot with this women group. In 2010, the One Village, One Product of the Royal Government of Cambodia had conducted an exhibition of their products that the Fisheries Product is one of their products too.

3. **Institutional Research Collaboration:** This project "Development of Alternative to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin Cambodia and Vietnam: Implications for Livelihoods, Production and Markets" provided opportunities for international travels to participate in international conferences and workshop which this opportunity was not only enhanced institutional and staff capability but also established networking and linkages between and among the research institutes, universities, and development institutions around the world.

DISCUSSION

The main goal of this investigation is for improving and ensuring food safety and values added of fermented fish paste product for local Cambodian consumers and the competitive market in Cambodia with the development of women fermented fish paste processing group/ association. These main goals take into account that the main driver of this project is the continued improvement and ensuring of our Cambodian traditional fisheries product food that everyone needs to eat everyday especially with the rural people who are more dependent on the fermented fish paste/*PRAHOC* for their food, and every year during the fishing peak season, every Cambodian needs to produce a hundred kilograms of *PRAHOC* to keep at home as food. They have their own technology in processing but they do not really nor care much about the hygienic and safe process and this may affect their health.

It also takes into account that: the fisheries food hygienic and safety can continue to play an important role in the food security, poverty alleviation and economies of our countries; the strong interdependency on our *PRAHOC* and raw material resources and also can increase local and intra-regional trade for low value/trash fish products; and there is increasing competition and conflict between the use of low values added to the product and lead to develop a policy and intervention on the fisheries product food safety.

The Investigation IV in the first phase of this project, the fermented fish processing method was not consulted well with the stakeholder and it has some mistakes and the definition of terms is not really professional and scientific term to use. For the second phase of this investigation, we can have proper and standardized format to develop of the Processing Technology, GMP/GHP Code of Practice (Appendix II) and Product Standard (Appendix III) used to improve their hygienic, safety and values added of the product throughout the trial and applied by the women *PRAHOC* processing association/group to see the effectiveness and efficiency of this standard and code of practice that we already drafted and what level our processors, traders, and fisheries officers can adapt and practically benefit from it and consume. So the new AquaFish fermented fish paste/*PRAHOC* Technology Development, GMP/GHP Code of Practice, and Product Standard Development need more time to thoroughly test and conduct more experiments of this standard and code of practice and finally result in the maximization of its level of effectiveness and efficiency before submitting it to MAFF, ISC and *Codex Alimentarius* for their approval as the national standard.

CONCLUSION

The project addressed a critical gap in terms of institutional capability of Fisheries Administration, especially to the Department of Fisheries Post-Harvest Technology and Quality which were not really considered and have ability to improving and ensure the quality, safety, and values added of the fish and fisheries products yet in term of the rules, regulation and standard, guidelines and code of practice and together with intervention to all stakeholders in the processing chain from farm to table due to lack of human resources and financial support that affect their implementation leading to problems on food security and profitability. The project has built up not only institutional and staff capacity but also established networking and linkages between and among the research institutes, universities, and development institutions around the world.

The project addressed the urgent need to solve the food security, safety and competitive market of fisheries products in fisheries sector in Cambodia with the formal national fermented fish paste/*PRAHOC* Technology Development, GMP/GHP Code of Practice and Product Standard Development and more than a 100 scientists, researchers, government fisheries managers and policy-makers, inter-government and non-government staff, extension agents, academic institutions, private sector, importer and exporters, fish farmers, fishers, fish traders, fish processors, and consumers can have a better understanding and use of *PRAHOC* processing better with the best practice standards and code of practice to improve the quality and safety, values added for this product and market opportunities. 2000 poor households in Cambodia, including women, who rely on fermented fish paste processed products will have improvements in product quality and safety and also 2000 poor households in Cambodia, including women members of the households who process low value/trash fish, will be better informed about potential improvements in processing practice; values added product development opportunities; and market opportunities toward increasing their income. On the other hand, this investigation can give long-term direct impact on at least a million of people who will benefit from eating healthy fermented fish paste food across the country in support of national poverty alleviation and increasing the fishing pressure in order to sustain the natural resources management and development.

LESSONS LEARNED IN IMPROVING FOOD SAFETY AND VALUE ADDED PRODUCT DEVELOPMENT FOR *PRAHOC* (FERMENTED FISH PASTE) IN CAMBODIA.

A number of lessons learned will be reported from the investigation – Maximizing the utilization of low-value or small-size fish for human consumption through improving food safety and value-added product development (fermented fish paste) through the promotion of fish processing women's groups/associations in Cambodia. The overall objective of this investigation was to work with women to improve and ensure food safety and value-added fermented fish paste products for local consumers, the competitive markets in Cambodia, and the development of women fish processing groups/associations through the development and extension of the fermented fish paste technology development; Good Manufacturing Practice (GMP)/Good Hygienic Practice (GHP) Code of Practice; and fermented fish paste product standard to apply to adopt and meet national and international market requirements. The location of the activities was *Siem Reap* Province.

An important lesson learned was the difficulty in obtaining approval at national and international levels for the *PRAHOC* standards. In the approval process, there is the need for approval from the Minister of the Ministry of Agriculture, Forestry, and Fisheries (MAFF); the President of the Institute of Standard Cambodia (ISC); the Ministry of Industry, Mines, and Energy (MIME); and the International *Codex Alimentarius* Union. Currently, we are waiting for the MAFF Minister's approval. During the process of the development of these standards, at every meeting and consultation there were a lot of comments which provided many ways to develop the standards for only the national market. But some participants stated that we must develop the standards to meet the international market requirements because every year our *PRAHOC* is exported to the neighboring countries, especially Thailand. In Thailand, the *PRAHOC* is reprocessed, packaged and labeled with the brand name of *PRAHOC Siem Reap Province,* but labeled as "Made in Thailand". It is felt that the value added for the product is lost to the Cambodian people. Due to these reasons, the MAFF leaders decided to develop the standards for the *PRAHOC* product that can be accepted by both national and international markets. But it is taking time to get approvals from the MAFF Minister and also the ISC president and EU *Codex Alimentarius*.

During the development of the product standards, we also applied these best processing practices through the women *PRAHOC* processor groups/associations in order to try and test the effectiveness and efficiency of the standards. During the *PRAHOC* sample testing, we found out that some samples are very unsafe for human consumption due to poor processing and preserving/maintaining conditions along the value chain. The Cambodian people do not seem to care about food safety and they care only about how to fill their stomachs. So it is very difficult for the government authorities, especially the Fisheries Administration, to require standards. During the organizing of the women *PRAHOC* processor group/association, people were not willing to participate in the group/association, and no one was willing to apply the standards. They stated that why do they need to participate as it is a waste of money and we spend much time for what reason? The processors do not follow any standard or apply any GMP/GHP code of practice, but they still cannot meet the demand of their buyers or consumers. These issues are raised not only by the processors, but also with people at the government management level, as they don't know and consider much and also understand about the side effects and hazards from the fisheries product food safety that we did not do it in the proper ways. The project worked to convince the processors about the importance of food safety, especially in fisheries products, through conducting trainings on critical hazards in the fisheries products and production. It also conducted monthly meetings with our fisheries administration in order to involve them in fisheries food safety activities. The project also developed some programs related to food safety in fisheries through broadcast mass media such as national TV and radio. There is now a slow development to better understanding and support of the need for food safety issues and best practices on *PRAHOC* processing standards development.

There are several other conclusions and lesson learned from this investigation on improving the food safety and value added product development of *PRAHOC* through the promotion of fish processing women group/association in Cambodia:

- At present in a poor country like Cambodia the people's perspective is on basic needs and there is limited concern about food safety standards.
- In Cambodia the management system are very complicated of bureaucracy system to follow and have their-own belief and trust that lead to have some issue on the delay result of the project outputs.
- The Cambodian people are still limited in their knowledge and awareness about food safety, especially from fisheries product and production
- The project has been able to begin to develop greater understanding from government, processors, consumers and other stakeholders on food safety issues and the need for food safety standards and best practice. Some even ask when can we finalize and approve the standards from the MAFF Minister and ISC president.
- In order to maintain the effectiveness and efficiency of the project funding, support should be best ways needed to integrate and harmonize with our 10 years Fisheries Administration Strategic Plan for next step activities.
- In order to finalize the best practice and standards we need to collaborate and integrate with other projects, such as The Promotion of One Village, One Fisheries Product (FOVOP). This project already has a brand name and it fully understood by everyone. The development of the *PRAHOC* standard should be understood as being one special and unique fisheries product which is certified as to product quality and safety with the FOVOP Logo and Stamp of approval and marketed through the National One Village One Product (OVOP) chair by Prime Minister Hun Sen.
- To be more successful we should have some cooperation and collaboration with a university for student research and sharing of expertise, technology and equipment.

It is suggested to continue future action and implementation of this work in order to finalize the best practice for *PRAHOC* technology development, GMP/GHP code of practice, and product standards development through conducting research experiments and trials to find the most effective and efficient standard for the national and international markets. To be more effective, the project should obtain more support in actual demonstration through the whole processing chain to make sure that everyone can see a real benefit with their own eyes. The best practice and standards can benefit Cambodians with safe fish food products to alleviate poverty, increase the economic contribution from fisheries products and production, and Cambodia can maintain their brand name of their unique products.

QUANTIFIABLE ANTICIPATED BENEFIT STATEMENT

This investigation will provide direct and indirect benefit stakeholders such as: the target beneficiaries are the fish processors and fish traders, who are primarily women, who would get better price for their improved quality of the product, and fermented fish paste consumers, who will get a safer product, and would be able to access better markets having complied with quality and safety requirements of these markets. The impact of the project will benefit the entire fisheries sector by improving the livelihoods of Inland and coastal fishing communities, and the women in those communities, generating better products through improved processing and packaging labeling techniques, facilitating access to new markets.

One student was supported and involved in the project through thesis research, but in this project we are not lucky enough to get student thesis because our student passed away in January 2011 after the USAID team came to Cambodia for their Monitoring and Evaluation work.

The National Fisheries Post-Harvest Sector will have formal national standard and code of practice and guideline on Fermented Fish Paste on Product development technology development, GMP/GHP Code of Practice, and Product Standard Development that finalized and approved by MAFF, ISC and future plan approve by the International *Codex Alimentarius* used to control product quality, safety, values added and marketing and can serve as a road map for future management and development.

A total of 100 scientists, researchers, government fisheries managers and policy-makers, inter-government and non-government staff, extension agents, academic institutions, private sector, importer and exporters, fish farmers, fishers, fish traders, fish processors, and consumers will have a better understanding and use of *Prahoc* processing better with the best practices guidelines to improve quality and safety, values added for this product and market opportunities.

A total of more than 2000 poor households in Cambodia, including women, who rely on fermented fish paste processed products, have improved knowledge and practices in product quality and safety, and help to extend more of this important advantage to many processors and consumers in Cambodia.

2000 poor households in Cambodia, including women members of the households who process low value/trash fish, are better informed about potential improvements in processing practices, value-added product development opportunities, and market opportunities toward increasing their income.

Nowadays, Cambodia can get many benefits that we could not quantify or imagine from this - project support from USAID as direct and indirect impact in terms of soft- and hardware to help our country especially the national government as we still seek government support, and many millions of Cambodians' awareness and understanding about food safety especially. *PRAHOC* is a very traditional food and ingredient especially for the rural people. More than 80% of the total population, and even our management level people too, all know the impact on their health of consuming and producing unsafe and unhygienic *PRAHOC* products. This knowledge and understanding can help them add value and get more income from safe and hygienic practices and can contribute to alleviate poverty and help the sustainability of our natural resources especially for fisheries resources management, conservation and development, even with being confronted by climate change that is a global warning too just, through national (TV, radio) media mass broadcast of all events/activities relating to this project support during the development of this *PRAHOC* standard and guideline process such as conducting consultation workshops, trainings, meetings with the stakeholders.

So I can conclude that after this 2-year project I can observe that our country has many long-term and short-term benefits such as: all national to sub-national government management levels have more awareness and understanding and coordinated application and assignment of priority to it when they consider it as a national policy; and stakeholders in the processing chain from farm to fork now also begin to be aware and have understanding about applying all concerns about the hygienic and food safety issues together with the values added to increase their income and also concern about *PRAHOC,* our traditional produc that every year we export thousands of tons of the semi-final *PRAHOC* product to Thailand for packaging to meet the international standard but get labeled as **"Prahoc Siem Reap**[1] *but* **Made in Thailand".** So with this project, we hope we can get back our brand name from Thailand and we can finish the product ourselves and then export this final product and realize higher profits from applying these high standards and guidelines.

[1] Siem Reap is one province in the very popular Angkor Wat Temple area, which makes for a very good brand name as "Prahoc Siem Reap". "Prahoc made in Siem Reap" will impress a consumer that the product will be delicious and can command a very high price.

ACKNOWLEDGEMENT

The authors wishes to express their deep gratitude and heartfelt thanks to the United States Agency for International Development (USAID) and the people of America for its financial support to the project implementation as well as to the Aquaculture and Fisheries Collaboration Research Support Program (AquaFish CRSP) Management Entity Director, Dr. Hillary Egna, for her patience, encouragement, untiring support, and guidance until the completion of the first phase of project implementation. Her advice has been a constant source of inspiration and her moral support is deeply appreciated.

Sincere thanks and appreciation are extended to Dr. Robert S. Pomeroy (US Lead PI), Dr. Sylvain De Guise, and Tessa Getchis, from the University of Connecticut, USA, Dr. David Bengtson and Dr. Chong Lee, from the University of Rhode Island, USA, for their constant assistance and advice to improve and complete the project implementation.

Deep appreciation and special thanks are wished upon all the AquaFish CRSP Management Entity staff and officers at the Oregon University for sharing their knowledge, experiences, and guidance.

Special thanks to H.E. Nao Thuok, Director General of the Fisheries Administration, and to all Fisheries Administration Staff from all central like Dr. Leng Sovann, Deputy Director of Department of Fisheries Post-Harvest Technology and Quality, and some support staff of this department and also from all of the provincial cantonment, especially Siem Reap Province that support to establish the women fermented fish paste associations/group and trial applied the best standard and code of practice of the fermented fish paste technology development, GMP/GHP code of practice and Product Standard Development until achieving better result and fruitful participation in the consultation discussion, and promoted extension of these knowledge to all relevant stakeholders especially fishers, farmers, processors, traders, consumers, students and local authorities regarding improving and ensuring food quality, hygienic and safe traditional and popular fisheries products (where we used to have very low safety) and higher marketability.

Also very special thanks to H.E. Ping Siv Lay, President/Director general of Institute of Standard of Cambodia, and his colleagues for their support, guidance, and help in the further approval of our finalized draft on Fermented Fish Paste/*PRAHOC* Technology Development, GMP/GHP Code of Practice and Product Standard Development for the national standardized use of Cambodia.

Sincere thanks and appreciation very much to the FAO Expertise especially, Dr. Iddya Karunnasanga, Senior Officer of Fishery Industry of FAO, Rome, Italy, for their strong support and guidance on the GMP/GHP Code of Practice and Product Standard Development.

Finally, the author would like to delicate this work this work to the respondents, *PRAHOC* processors, traders, fishermen, fisheries communities, and local authorities in Cambodia who made time out of their busy schedules for the interview.

This investigation will provide direct and indirect benefits to stakeholders such as: the target beneficiaries are the fish processors and fish traders, who are primarily women, who would get better prices for the improved quality of the product; fermented fish paste consumers who will get a safer product; and better market access having complied with quality and safety requirements of these markets. The impact of the project will benefit the entire fisheries sector by improving the livelihoods of inland and coastal fishing communities, and the women in those communities, generating better products through improved processing and packaging labeling techniques, facilitating access to new market.

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Appendix I: Prahoc Test Report

REPORT OF THE TESTING OF PRAHOC PRODUCED IN CAMBODIA

Prepared by Dr. Davin Uy

I. INTRODUCTION

PRAHOC is produced in Cambodia by natural fermentation of fish and salted for long preservation. Most of Cambodians are using PRAHOC for cooking for improving the taste and aroma of soups and other various Cambodian foods. Some people are eating PRAHOC without cooking. The natural fermentation is done by keeping the cleaned fish, more or less reduced fat for preserving PRAHOC against the rancidity, for 12 to 24 h to allow the natural fermentation, then the salt is added in excess quantity for preservation. The juice can be used as fish sauce production and the fish paste with salt was matured for several days to weeks for desired aroma. Normally, the salt sensitive microorganisms were eliminated after the salt addition. Some producers use $NaHSO_3$ for whitening the product for long storage. However, excess amount of this additive may cause the health implication.

The microorganisms developing during the natural fermentation and the possible toxins released by those microorganisms are not yet understood. The remained microorganisms after the addition of excess quantity of salt have not yet studied.

In this report, we are focusing on the analysis of PRAHOC for the basic parameters for better understanding of its composition. Certain tested parameters are for understanding the preservation, while the testing for certain microorganisms surviving in various PRAHOC collected from different places and producers are for understanding its risks. The following parameters are tested: Humidity, pH, Total Protein, Amino Nitrogen, Water Activity, Salt Content, Fat Content, Total Phosphorous, Total Volatile Based Nitrogen, Sulfide ($NaHSO_3$), Total Bacteria Count, Enterococcus, Fecal Coliform, Escherichia Coli and Staphylococcus Aureus. The result of the testing can be used for evaluating the qualities of PRAHOC and allow us to understand its condition for preparing the safe PRAHOC in Cambodia in the future.

II. SAMPLE RECEPTION AND ANALYSIS

15 samples of PRAHOC were received on 1 May, 2011 and the analysis was terminated on 30 May, 2011. The parameters of analysis are the following:

- Humidity is for evaluating the dry mass which can calculate the nutritional quality.
- pH is reflecting the fermentation behavior. pH is low when lactic bacteria was active during the fermentation or high pH is caused by the microorganisms releasing the ammonia during the fermentation.

- Water activity (Aw) and salt content can explain the preservation. High salt content results in low Aw value which is good for preservation during a long storage.
- Protein content is the main nutritional value of PRAHOC.
- High fat content increase the nutritional value but risk the rancidity during the long storage.
- The amino nitrogen and the volatile based nitrogen are the parameters indicating the PRAHOC fermentation and maturation. Long fermentation and/or maturation, result in increasing the amino nitrogen content and the volatile based nitrogen contents.
- The phosphorous content is explaining the possible presence of bone in the PRAHOC.
- The test of $NaHSO_3$ can evaluate if the producer added this substance of whitening PRAHOC

IV. CONCLUSION

The obtained results allow us to conclude as the following:

(i) ***Nutritional quality***: the total protein and fat contents range from 11 to 21% and from 0.16 to 12.5% respectively, but it is unlikely to be the source of protein as small quantity is consumed for each meal. Some PRAHOCs with bone present higher phosphorous content.

(ii) ***Preservation***: we observe that the salt content ranges from 14 - 35%, while some halophilous microrganisms are still active for the salt content less than 20%. Low in water activity value (about 0.45) will not allow the growth of most microorganisms. The high fat content in some samples may promote the rancidity during the preservation unless antioxidant is used.

(iii) The use of whitening ***chemical additive*** ($NaHSO_3$) was high in one sample while traces of $NaHSO_3$ in other sample may be originated from the degradation of sulfurous amino acid (cystein).

(iv) ***Bacteriological quality***: all tested samples present very high total plate count and pathogenic bacteria, however, fecal coliform and Escherichia coli were not present as these bacteria may be killed during the addition of salt during the processing. Thus, it is not safe to consume the uncooked PRAHOC.

V. PERSPECTIVE

As the preparation of PRAHOC is done by the natural fermentation which promotes the growth of both non-pathogenic and pathogenic microorganisms, it is necessary to study the process in detail to find out the useful non-pathogenic microorganisms responsible for PRAHOC fermentation. In this optic, the technology to produce the safe PRAHOC using the safe ferment will be developed.

Phnom Penh, 30 May, 2011

Signature

Dr. Davin Uy
Manager

Analysis of Prahoc samples

N	Parameters	Unit	A submitted firstly	B	C	Jar-1	Jar-3	7 days	10 days	15 days	KSP-I-3	KSP-I-3 red cap	KSP-II-3 red cap	KPCH-I-1	KPCH-II-2	KPCH-III-1	Lucky
1	Humidity	g / 100g	59.5	50.1	37.1	56.5	57.5	63.8	53.3	48.8	53.6	49.7	49.0	52.7	51.8	54.4	56.8
2	pH	-	6.34	5.80	5.80	6.65	6.64	7.56	6.19	6.14	5.62	5.50	5.66	6.15	5.89	5.50	5.58
3	Total Protein	g / 100g	18.6	18.1	11.4	19.0	21.4	19.2	19.3	20.2	18.0	15.5	18.4	16.7	19.0	16.3	18.4
4	Amino acid nitrogen	g / 100g	2.32	0.428	0.238	0.377	0.423	0.587	0.222	0.326	0.340	0.431	0.409	0.399	0.645	0.504	0.481
5	Water activity (Aw)	-	0.77	0.47	0.47	0.47	0.47	0.44	0.48	0.48	0.48	0.47	0.48	0.47	0.47	0.47	0.48
6	Salt (NaCl)	g / 100g	25.7	28.5	35.2	28.6	21.9	14.2	20.8	14.0	26.7	17.7	26.7	21.7	23.8	23.1	26.6
7	Lipid content	g / 100g	0.16	1.64	5.67	0.22	0.08	5.03	3.77	12.49	5.20	9.36	2.34	4.17	4.49	4.26	1.73
8	Total phosphorous	g / 100g	< 0.001	0.23	0.41	0.09	0.26	0.38	0.24	0.31	0.27	0.18	0.26	0.62	0.44	0.13	0.09
9	Total volatile base nitrogen	g / 100g	0.48	0.020	0.003	0.008	0.004	0.019	0.014	0.014	0.007	0.022	0.004	0.014	0.007	0.006	0.007
10	$NaHSO_3$	mg / 100g	95	3.56	4.49	7.57	1.69	2.63	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.85	1.79	0.84	0.86
11	Total Plate Count	count/ g	588900	40700	216900	7800	125000	26900	59600	327800	105200	152700	10700	7000	6900	3000	32700
12	Enterococcus	count/ g	0	0	0	0	0	0	0	29180		0	0	3160	0	0	0
13	Fecal coliform	count/ g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Escherichia coli	count/ g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Staphylococcus aureus	count/ g	1600	1400	0	0	0	80	180	0	400	0	330	2800	130	100	260

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FISH PROCESSING: GHP/GMP CODE OF PRACTICES AND PRODUCT STANDARD FOR PRAHOC

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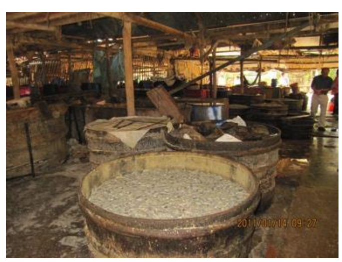
First Edition: November, 2011








Appendix II: Fish Processing and GHP/GMP Code of Practices for Prahoc

1. SCOPE

- These technical standards defines the basic conditions for safety and hygiene assurance for establishments that process commercial fermented fish paste (PRAHOC) fit for human consumption.
- These technical standards are applied to fermented fish paste (PRAHOC) that takes fish as a main raw material and are made through the corresponding process.

2. TERMINOLOGY AND DEFINITIONS

-Fish Paste (PRAHOC) is a Cambodian traditional product prepared from fermented freshwater fish. This product is consumed as is or used as a condiment after fermentation for three months minimum. (Refer to research output and consultation with fish processors and post-harvest fisheries stakeholders).

-Fish Paste (PRAHOC) is a processed fishery product prepared by a series of processing steps which include washing, heading, scaling, salting and fermenting in the jars.

2.1 Processed PRAHOC Products

-Boneless PRAHOC: have undergone a series of processing steps which include raw material receiving, first cleaning, heading and filleting, second cleaning, first soaking (for whole night), first draining, first salting and kneading, storage not longer than 36 hours, draining for two days and one, second salting, second draining (for 15-20 days), curing and sprinkle of brine water on drained fish, second fermenting in jars/wooden containers/cement concrete containers, packaging/ labeling, and distribution.

2.2. Cross- Contamination, transfer of contaminants (biological, chemical or physical) from any sources to PRAHOC products.

2.3. Clean Water, water that fulfils the requirements of the safety water.

3. Technical Standards for Hygienic Operation of PRAHOC Processing

3.1 PRAHOC Processing

3.1-1 Steps for Boneless PRAHOC Processing

Raw material receiving

↓

First cleaning

↓

Heading and filleting

↓

Second cleaning

↓

First soaking/fermenting (for overnight)

↓

Draining (1st) for 12 hours

↓

First salting and kneading (storage not longer than 36 hours)

↓

Draining for two days and one night

↓

Second salting

↓

Third draining (for 15-20 days)

↓

Curing and sprinkle of brine (brine is salt water) on drained fish

↓

Second fermenting in jars/wooden containers/cement concrete containers

↓

Packaging

↓

Labeling

↓

Distribution

3.1-2 Steps for Bony PRAHOC Processing

Raw material receiving

↓

First cleaning

↓

Heading and scaling

↓

Second cleaning

↓

Draining (1st)

↓

First salting

↓

Second draining

↓

Second salting and curing
↓
Fermenting in jars/wooden containers/cement concrete containers
↓
Packaging
↓
Labeling
↓
Distribution

3.2 Processing Step Description

3.2.1 Boneless PRAHOC Product

3.2.1.1 Receiving of Raw Material

- The raw material must be fresh; free from the contaminants; and kept in good hygienic condition.
- Salt must be of food grade; free from the contaminants; and kept in good hygienic condition.

3.2.1.2 First Cleaning

- Raw material must be carefully cleaned with clean water in order to avoid cross contaminations.

3.2.1.3 Heading and Filleting

- Fish shall be headed and filleted while avoiding cross-contaminations.

3.2.1.4 Second Cleaning

- Filleted fish must be carefully cleaned with clean water while avoiding cross contamination.

3.2.1.5 First Soaking/Fermenting

- Filleted fish after cleaning are subjected to soaking/fermenting with clean water for overnight while avoiding cross contamination.

3.2.1.6 First Draining

- Fish shall be drained in the shade for one hour at normal temperature while avoiding cross contamination.

3.2.1.7 First salting and kneading (storage not longer than 36 hours)

- Fish shall be mixed with salt at a 15-30 kg salt to 100 kg fish ratio and allowed to stand for 1 day for uniform salt diffusion while avoiding cross contamination.

3.2.1.8 Second draining

- Fish shall be drained under the sun light for two days and one night at normal temperature in the shade while avoiding cross contamination.

3.2.1.9 Second salting

- Fish shall be mixed again with salt at 10-15 kg salt to 100 kg fish ratio and held for 15 days while avoiding cross contamination.

3.2.1.10 Third draining (15-20 days)

- Fish shall be drained on the rack covered with a mosquito net for 15-20 days at normal temperature in the shade while avoiding cross contamination.

3.2.1.11 Curing and Sprinkling brine on drained fish

- Fish shall be cured and sprinkled with brine water while avoiding cross contamination.

3.2.1.12 Second fermenting in jar/wooden container/cement concrete container

- Salt shall be added enough to cover the surface layer followed by adding brine to pack the salt layer. Salted fish shall be stored for up to 3 months to allow fermentation.

3.2.1.13 Packaging

- PRAHOC shall be properly packed with food grade packaging materials while avoiding cross contaminations.

3.2.1.14 Labeling

- Labeling shall be done in accordance with labeling standards (CS001-2000).

3.2.1.15 Distribution

- PRAHOC shall be distributed in the packages that protect the safety and quality.

3.2.2 <u>Bony PRAHOC Product</u>

3.2.2.1 Receiving of Raw Material

- The raw material must be fresh; free from the contaminants; and kept in good hygienic condition.
- Salt must be of food grade; free from the contaminants; and kept in good hygienic condition.

3.2.2.2 First Cleaning

- Raw material must be carefully cleaned with clean water while avoiding cross contamination.

3.2.2.3 Heading and Scaling

- Fish shall be headed and scaled in order to avoid cross contamination.

3.2.2.2.4 First Draining

- Fish shall be drained for 2 hours at normal temperature in the shade while avoiding cross contamination.

3.2.2.2.5 First Salting

- Fish shall be mixed with salt at a 15-30 kg salt to 100 kg fish ratio and allowed to stand for 1 day for uniform salt diffusion while avoiding cross contamination.

3.2.2.2.6 Second Draining

- Fish shall be drained for 12 hours at normal temperature in the shade while avoiding cross contamination.

3.2.2.2.7 Second Salting

- Fish shall be mixed again with salt at 10-15 kg salt to 100 kg fish ratio and held for 15 days while avoiding cross contaminations.

3.2.2.2.8 Second Fermenting

- Salt shall be added enough to cover the surface layer followed by adding brine to pack the salt layer. Salted fish shall be stored for up to 3 months to allow fermentation.

3.2.2.2.9 Packaging

- PRAHOC shall be properly packed with food grade packaging materials while avoiding cross contamination.

3.2.2.2.10 Labeling

- Labeling shall be done in accordance with labeling standards (CS001-2000)

3.2.2.2.11 Distribution

- PRAHOC must be distributed in the packages that protect the safety and quality.

4 General Regulations on PRAHOC Processing Establishments

4.1 Location

- The establishments for PRAHOC processing must be located in a suitable area which is free from objectionable odors, smoke, dust and other contaminants coming from the surrounding environment; and from flooding caused by rainwater or high tide.
- If the establishments are affected by any of the above causes, necessary measures shall be taken to prevent their contamination.
  - Location of the establishments for PRAHOC processing must provide the following: after supply should be adequate for all operations of PRAHOC processing.
  - Transportation of raw materials and PRAHOC products must be readily available.

4.2 Design and Layout

- The establishment must be fenced off
- The design of a premises must permit safe and hygienic operation with easy cleaning. (generally, cleaning includes sanitation and disinfection)
- The premises must also be designed and maintained to prevent harboring of pest and contamination of smoke, dust, odors, etc.
- The premises must provide proper separation for various operations either by partition, location or other effective means.
- Adequate working space must be provided to allow for satisfactory performance of all operations and to ensure hygiene and safety.
- Areas used for nonfood operations must be separated from the food production area or the areas in which the products not fit for human consumption are produced.

4.3 Construction

4.3.1 General Requirement

- The building must be of sound construction and maintained in good repair, adapt to the nature and scope of the establishment, and ensure the hygiene and quality standards of PRAHOC products.
- The materials used in the construction of the floors, walls, ceiling, etc. must not release hazardous substances directly or indirectly to the PRAHOC products.

4.3.2 Surrounding of PRAHOC Processing Premise

- The concrete surrounding outside the building must be at least 1.2 m wide with a necessary slope for proper drainage
- The surrounding areas must be kept clean.

- The parking areas must be surfaced with concrete, asphalt, gravel, or similar materials to minimize dust and kept clean.

4.3.3 Floor of Processing Plant

- Floor must be paved with hard, durable, non-permeable and non-slip material without crevices and puddle, and easy to clean and sanitize.
- The junctures between floors and walls should be sealed to facilitate easy cleaning.

4.3.4 Drainage

- In any area which involves a “wet” operation:
- Floors must slope sufficiently at least 1:48 (2%) for liquids to drain to trapped outlets;
- Floor drains must be provided and be adequate in size, number and location to handle the maximum flow of water under normal working conditions.
- All drains must be constructed in such a way that odor is prevented from entering the facilities, screened to prevent the entrance of pests and vermin, and be easy to clean.
- Solid traps installed in conjunction with floor drains must be designed to enable adequate cleaning.
- Floor drains must not be connected with sanitary drainage. Where floor drains are connected to a rainwater drainage system, they must be designed and maintained to ensure that flooding of the premises does not occur.

4.3.5 Walls

- In rooms where PRAHOC product is produced, stored or transported, the walls must be constructed with durable and water-impervious materials and be light-colored and smooth.
- Any walls or parts that do not abut the ceiling must be capped to prevent dust accumulation. A minimum slope must be at least 45 degree.
- All piping, conducting-wires along the walls must be sunk in the walls or covered and fixed far from the walls 10 cm for easy cleaning and preventing the harboring of vermin.

4.3.6 Ceilings

- Must be constructed of smooth, durable, impermeable and light colored material, and should be easy to clean and not be flaked.

4.3.7 Windows, Doors and Vents

- Windows, doors and vents are not permitted open in areas where processed PRAHOC products are exposed, processed or packed.
- Open able windows and vents must be fitted with insect-proof screens which are easily removed.
- Window sills shall be sloped inward at least 45 degrees and be at least 1m from the floor to prevent the accumulation of dust.
- Doors and hatches shall have smooth, non-absorbent surfaces and shall be close fitting. If doors, windows and hatches are made from safety glasses, all joints between glasses and frames shall be sealed by silicon.
- Doors, hatches and other openings to outside of the building or where physical separation is required shall be installed with strip curtains, air curtains, or a self- closing device.
- Processing area shall not open directly to the machine room, toilets, and area where processing waste is loaded and stored.

4.3.8 Equipment and Utensils

- All equipment and utensils that may contact the product, must be: made of materials which do not transmit odor, taste or toxic substances, and are non-absorbent, resistant to corrosion, capable of withstanding repeated cleaning and disinfecting, smooth, and easy to clean.
- In case of using the concrete tub for fermenting, the contact surface must be smooth and free from toxic substances.

4.3.9 Transport Means

- The transporting vehicle must be suitable and clean, and loading and transportation must be conducted in such a way as to protect products from damage and potential sources of contamination, and to ensure the packaging integrity.
- The vehicle for transporting the raw materials must be equipped with an adequate chilling system.
- The transporting vehicle for final products must be operated while avoiding any damage and cross contaminations; and maintaining the packaging integrity

4.3.10 Waste Treatment System

4.3.10.1Wastewater Treatment

- The establishment shall have a wastewater treatment system and it must be maintained in good operation condition.
- Wastewater after treatment must satisfy the requirements for hygiene and safety standards. The untreated wastewater is not permitted to be discharged into the surrounding environment.

4.3.10.2Waste Handling

- The establishment shall have appropriate equipment for collection of waste to prevent odor and other adverse effects on the establishment and surroundings.
- Waste shall be collected and disposed from the processing area at least every 2 hours and shall not be stored in the processing area.
- The waste room shall be placed well away from the room or area where fishery products are handled. The waste room shall also have separate ventilation and be easy to clean and sanitize periodically.

4.4 Quality Control Facilities

4.4.1 Quality Management Team

- The establishments shall assign a Quality Management Team to ensure the relevant quality assurance activities planned and performed.
- The QM staff and production supervisors shall have a broad experience and be properly trained in relevant fields such as fish processing, quality control and sensory evaluation.

4.4.2 Hygiene Facilities

4.4.2.1 Hand Washing Facilities

- The establishment must have sufficient hand washing facilities adjacent to personnel entrances to the processing area and in the toilets.
- These facilities must be provided with non-manually operated taps, an adequate supply of clean water, soap dispensers, and suitable and sufficient hygienic means of drying hands;
- In processing area of high risk products, there must be both hand washing and sanitizing facilities.
- Notes must be clearly posted near the food handling area entrances directing personnel to wash their hands on entering or re-entering processing areas.

4.4.2.2 Boot Sanitizing Basins

- Establishment must provide boot sanitizing basins (footbaths) at the entrance of each processing room so that every person entry processing area shall sink their boot in it
- Sanitizing basins must have:
  - o Sanitizer-containing water with a depth more than 15 cm, a drainage hole to replace water periodically, preferred sanitizers are iodopher at 200 ppm and quaternary ammonium compound (Quat) at 400-600 ppm (chlorine is not recommended since it is easily deactivated).
  - o Drainage water from hand washing basin must not be flowed into the boot sanitizing basins.

4.4.2.3 Changing Rooms

- The establishment must have changing rooms that are located at a suitable place with proper dimension.
- Changing rooms must:
  - o Have no door opened directly to processing areas;
  - o Be separated for man and woman, include sufficient storage for personal belongings and provide a separate space for keeping clothes.

4.4.2.4 Equipment for Washing Up and Disinfection

- The establishment shall have adequate washing-up facilities for cleaning and sanitizing processing equipment and utensils.
- There shall be separate cupboards, shelves or rooms closed and locked for cleaning and sanitizing agents, etc. Such cupboards or rooms shall be appropriately placed and well ventilated.
- Cleaning and sanitizing agents must be labeled with clear information of the name and necessary directions for use.

4.4.2.5 Sterilizing Facilities

- If the sterilizing medium of a sterilizing facility is not water, the method of sterilization must be approved by Fisheries Administration.
- If the sterilizing medium is water, the facility shall be fitted with suitable means of supplying hot and cold water in sufficient quantities.
- Sterilizing facilities must be constructed with corrosion resistant materials and easy to clean.

4.4.2.6 Hygienic Operating Conditions

4.4.2.6.1 General Provisions

- PRAHOC product shall be handled and stored in such way as to prevent contamination and spoilage.
- Cross-contamination of PRAHOC products shall be avoided at all stages from raw materials to marketing of PRAHOC finished products.
- Final products shall be kept at ambient temperature.
- Persons who handle unwrapped PRAHOC products must not at the same time carry out other operations that may contaminate the products.
- PRAHOC products, crates, cartons, basins and containers shall not contact and not be placed on the floor.
- Dogs, cats and other animals must not be admitted to the premises.
- It is prohibited to use tobacco, spit, eat or drink on premises.
- Any person, who enters production areas, shall wear protective clothing, a hair restraint and protective footwear.

- Any other products (e.g. animal feeding stuff, waste, rejects) that may have an undesirable effect on PRAHOC product for human consumption, shall not be produced or stored together with them.
- Vehicle that emits contamination (soot, etc.) shall not be used in premises where PRAHOC products are produced.
- No objects or equipment that are irrelevant to the work of the establishment shall be stored or used on the premises, including equipment and objects that are not permitted used or that are no longer in use.

4.4.2.6.2 Maintenance

- The maintenance program shall be planed and implemented by the establishment such as self inspection on status of premises, equipment, machines, utensils, and maintenance or repair in good conditions.

4.4.2.6.3 Water Supply

4.4.2.6.3.1 General Requirements

- Water used for PRAHOC processing must be clean.
- An ample supply of water must be available throughout an establishment with adequate pressure and suitable temperature, and meet the requirements mentioned in the appendix-A.

4.4.2.6.3.2 Water Treatment

- If necessary, the water shall be treated by filtration and chlorination in order to achieve the water quality standards in Appendix A.
- If the water used in the plant receives additional treatments prior to use (e.g. use of ultraviolet treatment...), this shall be done in accordance with the instructions of the manufacturer of any equipment or chemicals used.

4.4.2.6.3.3 Storage of Water

- The establishment should possess an adequate water storage tank with sufficient capacity to supply the requirements of the establishment when operating at maximum capacity.
- The water storage tank shall be well constructed and the internal surfaces shall be smooth and impermeable using cement of acceptable quality.
- Each water storage tank shall be provided with an impermeable hatch, which permits entry for cleaning and inspection purposes. The design of hatch shall protect against the entry of rainwater or any water, which may flow out of the plant.
- Each water storage tank shall be protected by adequate screening of any ventilation pipes.
- The area surrounding each water storage tank shall be maintained clean and free of accumulation of rubbish, dust, water and other materials, which could contaminate the water inside.
- The establishments shall set up a plan to clean periodically the water storage tank.

4.4.2.6.3.4 Water Piping System

- There shall be cleaned water supply system used for processing operations that are separated from the unclean water supply system. There shall be a flow diagram for each supply system.
- The outlets and distribution lines of clean water in processing area shall be numbered both in practice and on the scheme to serve the sampling for analysis in every month.
- Unclean water may be used for subjects that is not food, must be carried in completely separate lines, identifiable, preferably by color, and with no cross-connection with the system carrying clean water.

4.4.2.6.3.5 Ice Supply

4.4.2.6.3.5.1 General Requirements – Ice used to chill fish shall be:

- made from clean water;
- made, stored, transported, distributed and used in hygienic conditions;
- Samples of ice shall be taken regularly for microbiological tests;
- The microbiological criteria for ice used for chilling fish shall meet the water quality standards in the appendix-A.
- In case of using ice manufactured in other than the establishment, those establishments must meet all requirements of hygiene and safety.
- An ice transportation unit shall be designed so that it can be easily cleaned, be constructed of hard, durable, noncorrosive materials, and shall not release hazardous substances to the fishery products.

4.4.2.7 Pest Control

- The establishment shall have a written effective plan for the control of rodents, birds, insects and other pests.
- If poisonous substances are used, these shall be stored in the lockable cupboards or rooms, and be used in such a way that they do not contaminate fish and fishery products.

4.4.2.8 Cleaning and Sanitizing

- There shall be an assigned staff or team to carry out a cleaning program adapted to the nature and scope of the establishment.
- Fittings and equipment surfaces that come in contact with PRAHOC products and may contaminate, shall be cleaned and sanitized after middle shift rest and also when the shift is finished.
- Hosing down of premises, equipment, etc. shall be restricted so as to avoid unnecessary splashing. Floors and equipment or utensils shall not be hosed when there are unwrapped fish products in the same room.
- Cleaning agents and disinfectants used must be on the permitted list and appropriate for the purpose.
- All remains of such substances on surfaces that can come into contact with PRAHOC products must be rinsed away with clean water before the equipment is used again.

4.4.2.9 Personal Hygiene

4.4.2.9.1 General Requirements

- Persons who contracted infectious diseases or carry an infection that can be transferrable to fish and fishery products, or who have infected wounds, boils or other skin infections must not participate in working operations whereby they can directly or indirectly contaminate fish and fishery products.
- People, who are working with fish and fisheries product, shall have medical examination every year in accordance with the regulations of Ministry of Health.
- Personal Health documents shall be kept properly by the establishment and made available to the inspection authority upon request.

4.4.2.9.2 Working Clothes

- Persons, who handle fish and fishery products, must wear protective clothing and footwear, head-covering that encloses the hair and the beard or moustache, or both. If gloves are used, they shall be in sound, clean and sanitary condition.
- The working clothes shall not have outer pockets and be differentiated for each processing area. Especially, the person who is working in the high risk areas.
- Protective clothing shall be cleaned every day by the establishment.
- Protective outer clothing used in food handling area must not be worn outside the processing areas.

- Personal property, articles of clothing and objects irrelevant to operations shall not be stored in rooms where fish products are produced.

4.4.2.9.3 ***Personal Cleanliness***

- Person who handles PRAHOC products shall wash their hands: on entering the fishery product handling area, after using the toilet, after touching the nose or mouth; or after contact with any contaminated substances.
- Any cut or wounds on hands and forearms shall immediately be covered by a suitable water-proof dressing after proper treatments.
- Personal behavior; People engaged in fish and fishery products handling activities should refrain from behavior, which could result in contamination of PRAHOC product, for example:
  - Smoking;
  - Spitting;
  - Chewing or eating;
  - Sneezing or coughing over unprotected PRAHOC products.
- Personal accessories such as jewelry, watches, pins or other items should not be worn or brought into fish and fishery products handling areas if they pose a threat to the safety and suitability of food.
- Cosmetics shall not be used by the workers during working.

4.4.2.9.4 ***First Aid Box***

- The plant shall be provided with a first aid box, which should contain at the minimum: a sufficient quantity of impermeable dressings, antiseptic cream, cotton wool, adhesive tape, and a suitable wound disinfectant.

4.4.2.10 ***Training***

- All staff shall be trained on GMP, GHP, and safety work at the beginning and receive a refresher training every year.
- The workers must be trained before carry out their task and retrained every year on food hygiene, personal hygiene, good manufacturing practices, and work safety.
- The staff, which is using chemicals, shall be trained properly.

4.4.3 Packaging

- PRAHOC products should be packaged to protect safety, quality and physical integrity of products using an appropriate packaging system while avoiding cross contamination.

4.4.4 Transport

4.4.4.1 General Requirements Regarding Transport

- PRAHOC products shall be handled with care during loading, unloading and transport, to avoid damaging or soiling the packaging or products.
- Facilities used for transport of fish products may not be used for other products which may affect or contaminate the fish products, except when thoroughly cleaned and sanitized to ensure that fish products are not contaminated or adversely affected in any other way.
- Internal surfaces and any equipment in transport facilities for fish products shall be smooth and easy to clean and disinfect.
- PRAHOC products shall not be transported by means of equipment that is not clean.
- The transport equipment and means shall be cleaned and sanitized before and after each transport.

5 Safety and Quality Management System

5.1 Traceability and Recall of Defective Products

- The enterprise must elaborate regulations in writing for traceability and recall of products in case food safety hazards are found after the products have been shipped.
- The enterprise must carry out the traceability procedures, and when necessary, must notify the concerned parties (authorities and customers) and recall of defective products.
- When establishing the traceability procedures, the enterprise must elaborate very specific measures to ensure that they are able to recall products that have defects both inside and outside the enterprise.
- Documents concerning procedures on traceability and recalling defective products shall be kept in files in accordance with stipulations.

5.2 Monitoring Program

- The enterprise must monitor for all steps of both processing chains and GHP/GMP operation condition from receiving of raw materials until products distribution.
- Given the fundamental importance of this program, it is critical to employ effective monitoring procedures. A failure in monitoring procedures will result in a significant risk in the production of safe food. All fish processing establishments are expected to have an effective cleaning and disinfection program in place, as there is such a wealth of information on both the importance of this area from a food safety perspective and the means to develop and implement an effective cleaning and disinfection program.
- The most common form of monitoring involves the senses, e.g. visual inspection after cleaning, smelling the presence of offensive odors, and feeling for greasy surfaces.
- This monitoring will be done by supervisors and/or quality assurance staff every time a cleaning operation is undertaken. Monitoring will also be continuous during processing operations.
- The manual needs to detail the monitoring of both the cleaning and disinfection procedures used in the factory. It will describe what is being monitored, how the monitoring is achieved e.g. visual inspection, test kits, etc., who will do the monitoring and how frequently the monitoring is undertaken.

5.3 Corrective Actions

- When monitoring detects problems with any of steps or GHP/GMP operation conditions, an immediate evaluation shall be required to determine what steps need to be taken.
- A step needs to be taken in order to identify suspected products and remove them from the distribution chain until their safety has been established.
- If it becomes clear that all processing steps have not met the GHP/GMP operation requirements, appropriate corrective actions should be taken. In each of these cases, record keeping should follow indicating non-compliance if there is, and corrective actions to be taken and confirmed if they have resolved the problems.
- The manual needs to detail the corrective actions that will be taken in the fish processing establishment when the limits established in the monitoring procedures are exceeded. It also needs to detail the responsible person(s).

5.4 Record Keeping System

- The enterprise shall establish procedures governing documentation, checklists concerning QM implementation and regularly review QM records and documentation.
- Records and checklists associated with monitoring QM system must be prepared in such a way that they are clear and easy to understand by the users. They must be realistic, reviewed and approved by the authorized official before being in use or whenever changes are made.
- All documents and records must include at least the following information:

a. Name and address of the enterprise

b. Date, and time recorded and signature of person doing record
c. Results of monitoring
d. Date verified, and signature of official doing verification of the records.
e. Name or code of the product, lot of products related.

- A person(s) must be assigned to supervise and make records on-site at frequency stipulated in the checklist. Records of monitoring results must be kept without any correction, or changes.
- Documentation and records must be maintained in period depending on shelf-life of each type of product, with respect to legislation or commitment with the consumers. They must be kept for at least:

a. 2 years for frozen, processed products such as PRAHOC.
b. 2 years for manuals concerning operating of equipment or technology

- Record keeping might be done on computer. In this case, the enterprise must have internal guidelines detailing what contents to be maintained, computer operation practices, data handling, data saving, security, person in charge and others relating to preventing loss of data on computer.
- The enterprise shall assign (in writing) labor force for records review and audit at the following frequency:

a. Daily
b. Weekly
c. Monthly

- Overview periodically

5.5 Verification Program

- The enterprise shall verify all corrective actions. A failure in the verification program will result in a significant risk in the production of safe food.
- Verification of corrective actions is important for the next monitoring program.

6 APPENDIX A: Additional Quality Standards for Clean Water

6.1 Additional criteria

6.2 pH (The pH of clean water used in the processing of PRAHOC products should fall within the range 6.5-8.5).

6.3 Chlorine concentration

6.4 The concentration of chlorine in the water used in the plant should be less than 1mg/l (1ppm).

6.5 The addition of chlorine should be adjusted in order to maintain the specified concentration at the point of use inside the plant.

Delay of at least 30 minutes should be observed between the treatments of water with chlorine, and only that water treated by this way should be used for processing of fishery product.

Appendix III: Product Standards for PRAHOC

FOREWORD

Currently, the need of traceability in relation to food quality and food safety for consumers is increasing. The quality of fish and fishery products is an important concern of the industry and consumers. Deterioration of fishery products mainly occurs as a result of microbiological activity and biochemical and chemical changes during processing and storage. Raw material quality and processing conditions are the most important factors that affect the quality of fishery products.

PRAHOC (salted and fermented fish product) is traditionally popular in Cambodia. PRAHOC product has been shown to be safe for millenniums. Freshwater fish (Snakehead, Mud carp and Trichogaster and their family) are by far the most important species for salted and fermented fish processing. PRAHOC is one of the most important food products for the economy of Cambodia and is a traditional product. The traditional production of PRAHOC is a simple process in which freshwater fish are scaled, headed, soaked in brine or mixed with dry salt, piled up, and stored for fermentation. There are two types of PRAHOC: “PRAHOC Chaeng or Bony Fermented Fish Paste” (ordinary PRAHOC) with bones in and “PRAHOC Sach or Boneless Fermented Fish Paste” with bones removed. PRAHOC is one of the principal salted; fermented products consumed in Cambodia and are used in the preparation of many traditional dishes. Salt decreases the water activity of the product as it diffuses into food structure. Salting and fermentation preserve products and promote protein autolysis releasing savory amino acids and other flavors. This results in sensorial changes that make the final product more palatable.

Generally, the quality of the salted, fermented fishery products depends on the quality and chemical composition of raw material. In addition, the salt composition affects the quality of salted fish. Usually, edible salt as specified in the Cambodian Standards CS 0055:2007 is used in order to obtain the desired texture and flavor.

This product standard lays down general and specific requirements for salted, fermented fishery products (PRAHOC). Use of the standard is voluntary and the standard shall provide an unambiguous description and understanding of Cambodian fishery products.

REFERENCES

- Cambodian Standard CS 003:2003 on Fish sauce
- Cambodian Standard CS 0055:2007 on Edible salt (ordinary, washed and iodized)
- Cambodian Standard CS 001:2000 on labeling of food product
- CODEX STAN 233-1969 on sampling plans for prepackaged foods
- CODEX STAN 167-1989, Rev. 1-1995- for salted fish and dried salted fish of the Gadidae family of fishes
- AOAC testing methods 17th edition, 2000.

PRODUCT STANDARD FOR PRAHOC

1. Scope

This standard specifies type, requirements, hygiene, packaging, marking and labeling, sampling, testing and criteria for conformity for PRAHOC products that are made from freshwater fish for human consumption.

This standard does not cover the products that are made from marine fish in whole or any part.

2. Definition

For the purpose of this standard, the following definitions apply.

2.1 Fish: any of the cold-blooded aquatic vertebrate animals living in water and having fins, permanent gills for breathing.

2.2 PRAHOC: A salted, fermented fishery product that can be obtained by the traditional processing method which consists of heading, scaling, washing, salting, draining, drying and fermenting. This product has unique characteristics in terms of flavor and texture. The fermentation process transforms large molecules into smaller ones, primarily proteins, through hydrolysis the combined actions of micro-organisms and enzymes making the product flavorful.

2.3 PRAHOC Cha-eng (Bony Fermented Fish Paste): A PRAHOC product with bones in. Mostly, it is made from Cyprinidae family such as *Henicorhynchus lobatus/siamensis*.

2.4 PRAHOC Sach (Boneless Fermented Fish Paste): A PRAHOC product with bones removed. Mostly, it is made from snakehead (*Channidae*) or Trichogaster.

2.5 Salt: salt (sodium chloride) of an appropriate quality suitable for the purpose.

2.6 Contaminant: any biological or chemical agents, foreign matters or other substances that may compromise food safety or suitability.

2.7 Contamination: the introduction or occurrence of contaminants in food.

2.8 Pest: any unwanted and destructive insect or other animal that attacks food including birds, rodents, insects, worms and arachnids.

2.9 Water activity (a_w): Ratio of the water vapour pressure in the foodstuff to the vapor pressure of pure water at the same temperature. It is used to predict food product stability against microbial spoilage.

2.10 Whole fish: whole fish as captured,

3. Type:

The PRAHOC shall be available in two types as follows.

- PRAHOC cha-eng (Bony fermented fish paste)
- PRAHOC sach (Boneless fermented fish paste)

4. Raw materials

4.1 Fish: The whole fish or its part that is in a condition for human consumption, shall be used as raw material for the production of PRAHOC.

4.2 Salt: Edible salt such as ordinary, washed or iodized salts that comply with the requirements of Cambodian standard CS 0055:2007- edible salt (ordinary, washed and iodized), shall be used as a main ingredient for production of PRAHOC.

5. Requirements

5.1 General requirements

5.1.1 PRAHOC Cha-eng (Bony Fermented Fish Paste)

The product shall be prepared from the whole fish or its part as specified in Clause 2.3 in which fish is processed with bones in.

5.1.2 PRAHOC Sach (Bonless Fermented Fish Paste)
The product shall be prepared from whole fish meat or its part as specified in Clause 2.4 in which fish is processed with bones removed.

5.1.3 Free From Defect
The products shall be free from live insects infestation or part or whole dead body.

5.1.4 Free From Unsafe Additive
The products shall be free from any additive that renders it unsafe or unsuitable for human consumption except for edible salt specified in Clause 4.2.

5.1.5 Foreign Matter
The products shall be free from glass, sand, metals, woods, insects and dead insect fragments, and fungal contamination, dead rodents, worms and dead worm fragments and other extraneous materials.

- **PRAHOC Cha-eng:** Other than the extraneous matter mentioned above, the PRAHOC Cha-eng may contain its own bones or scales.
- **PRAHOC Sach:** Other than the extraneous matter mentioned above, the PRAHOC Sach shall have its own bones or scales not in excess of 0.01g/kg of the product.

5.1.6 Taste and Odor
The products shall have desirable characteristic as indicated in the Table 1.

Table 1: Sensory Parameters

Parameter	Requirements	Method of Test
Taste and odor	Having the natural taste and odor for the variety, without offensive taste or rancid or objectionable odor	Annex-A

5.2 Chemical Requirements
The PRAHOC shall have chemical properties conforming to those given in Table2.

Table 2: Chemical Properties

No.	Parameters	Requirements	Method of Test
1	Moisture, percent by mass, max	45%	Annex-B
2	Water activity (a_w), max	0.48	AOAC 950.46B
3	Salt content, percent by mass, max, calculated as NaCl	15 - 35%	AOAC 971.21
4	Acid insoluble ash, percent by mass, on a dry weight basis, max	1.5%	ANNEX-C
5	Protein, percent by mass	12 - 25%	ANNEX-D
6	Total volatile base nitrogen(TVB-N) (mg/100g)	0.008	Annex-E

5.3 Contaminants

5.3.1 The product may not contain contaminants like mercury, cadmium, lead and arsenic in the amounts of which are significant for human health.

5.3.2 Coloring Matters

No added coloring matters shall be used.

5.3.3 Preservatives

No preservatives shall be added.

5.4 Microbiological Requirement

Microorganisms in the PRAHOC product shall not be found to exceed the following amounts given in Table 3.

Table 3: Microbiological Properties of PRAHOC Product

No.	Microorganism	Requirement	Testing method
1	Total plate count	10,000/g	ISO 4833:2003
2	*Escherichia coli (E. coli)*	<230/100g	ISO/TS 16649-3:2005
3	*Listeria monocytogenes*	100/g	ISO\11290-1:1996/Amd.1: 2004
4	Yeast and Mold (cfu/g)	none	ISO 21527-2:2008

6. Hygiene

The hygienic requirements of production process should conform to the Cambodian Standards CS 084:2010 (Common principles and requirements for Food Hygiene).

7. Packaging

The PRAHOC product shall be packed in entirely enclosed packages and/or wrapped in suitable packaging materials which do not adversely affect the nature of the product. The containers or packaging material shall be cleaned and made from glass or plastic (PE, PET) that is suitable for packing food for human consumption and protects a product from contamination.

8. Marking and labeling

The labeling of the product shall be applied in conformity with the Cambodian standard CS 001:2000-labeling of pre-packaged food.

At least the following information shall be marked on each container.

a. Name of the product " PRAHOC cha-eng or PRAHOC Sach"
b. Name and address of manufacturer, packer or distributor
c. Trade name, if any
d. Net weight in g or kg
e. lot number
f. Manufacturing and expiration dates
g. Country of origin.

In case of foreign language is used, the meaning shall correspond to the above information.

9. Sampling

9.1 Definition:

9.1.1 Lot: Any consignment of Prahok of the same grade, packed in container of the same size, same time and bearing the same brand name, mark or trademark shall be considered as a lot.

9.1.2 Lot Size: Number of container units in a lot.

9.1.3 Sample size (n): The number of containers of prahok taken from the lot for inspection.

9.1.4 Acceptance Number (c): The number in a sampling plan which indicates the maximum number of defectives permitted in the sample in order to consider the lot as meeting the requirements of Standard.

9.2 Sampling Procedure

When drawing samples, the following precautions shall be taken:

9.2.1 The sampling instruments shall be clean and dry when used. When drawing samples for the microbiological examination, the sampling tools shall be sterilized.

9.2.2 The samples shall be kept in clean, dry glass or suitable containers or shall be kept in sterilized containers.

9.2.3 The sample containers shall be sealed air-tight and marked with necessary details of sampling.

9.2.4 The samples shall be stored in such a way that there will be no deterioration of the quality of the material before analysis.

9.3 Scale of sampling

9.3.1 Samples for testing shall be drawn at random from the same lot in accordance with the sample size given in Table 5.

Table 5: Sampling plan

Lot Size (Number of Containers)	Sample Size	Acceptance Number
not more than 4 000	6	1
4 001 to 12 000	13	2
12 001 to 24 000	21	3
More than 24 000	29	4

9.4 Preparation of the Sample for Microbiological Testing

Samples drawn for testing shall be prepared for microbiological analysis first. A sub sample of six (06) packages shall be selected from the packages selected as in 9.3.1. Approximately equal sufficient quantities of material shall be drawn from each package using an appropriate sampling instrument and transferred to six different sample containers.

9.5 Preparation of the Composite Sample

Composite samples shall be used to examine chemical residues and contaminants.

Approximately equal quantities shall be drawn from each package selected as in 9.3.1 using an appropriate sampling tool, and mixed to get a composite sample of sufficient size and transferred to a moisture proof sample container.

9.6 Number of Tests

9.6.1 Each package selected as in 9.3.1 shall be inspected for packaging, marking and labeling requirements, appearance, taste and odor and foreign matter.

9.6.2 The six samples prepared as in 9.4 shall be tested for the requirements given in 5.3

9.6.3 The composite sample prepared as in 9.5 shall be tested for the requirements given in 5.2 and 5.4

10. Criteria for Conformity

A lot shall be declared as it conforms to the requirements of the standard if the following conditions are satisfied.

10.1 The test samples satisfies all requirements given in clause 5.1 and 8

10.2 Each package inspected as in clause 9.6.1 satisfies the relevant requirements.
10.3 The result on microbiological tests as in clause 9.6.2 satisfies the relevant limits.
10.4 The composite sample tested as in clause 9.6.3 satisfies the relevant requirements.

11. Testing methods

The tests shall be carried out following methods described in forth column of tables 2, 3 and 4 and annex A to G.

ANNEX-A

INSPECTION AND ANALYSIS OF FLAVOR, ODOR AND DEFECT

A1 **Apparatus**
A1.1 Porcelain bowls
A1.2 Stainless steel spoons

A2 **Procedure**

A2.1 The product shall be inspected by a panel comprising at least 5 judges who are familiar with the factors governing the quality of the product. Each judge shall independently inspect the product and assign scores for deferent characteristics. The scoring system is given in Clause A2.2 and A2.3, respectively.

A2.2 The characteristics given in Table 6 shall be considered for scoring:

Table 6: Scoring for Sensory Test

Item	Full Score
Flavor	20
Odour	20
Defects	20
Total Score	**60**

A2.3 System of Scoring

The scoring of product characteristics shall be based on the classification as given in the Table 7.

Table 7: Scoring System

Score Classification			Inspection item
	Flavor	**Odor**	**Defects**
1 – 9	Poor	Poor	Poor
9 -14	Fair	Fair	Fair
14 - 20	Good	Good	Good

ANNEX-B
DETERMINATION OF MOISTURE

B1- Sampling

Collect samples in appropriate quantities from the designated lot. Homogenize each sample to a uniform mass. Transfer to an airtight container to prevent the loss of moisture.

B2- Determination of moisture

Weigh accurately about 5 g of the prepared sample in a moisture dish. Dry in an air oven at 110° C for overnight. Cool in a desecrator. Quickly weigh the dish.

Calculate Moisture as follows.

$$\text{Moisture (\%)} = \frac{M1 \times 100}{M2}$$

Where:

M 1 = Loss in g in the mass of sample
M 2 = Mass in g of the sample taken for test

ANNEX-C
DETERMINATION OF ASH INSOLUBLE IN DILUTE HCL

C1- Reagent

Dilute hydrochloric acid (HCl) -1+1 to 6N

C2- Procedure

Weigh accurately 2 g of the dried material (obtained after determination of moisture) in a crucible. Transfer to a muffle furnace, char at 200°C and keep at 550°C for few hours till grey ash is obtained. Remove after the temperature of muffle furnace drops to around 100°C and cool in a desiccator. Weigh to determine total ash, if desired. Add 25 - 30 ml of dilute HCl to the crucible and boil it for 10 minutes. Cool and filter it through Whatman filter paper No 42 or its equivalent. Wash the residue with water until the washings are free from chloride as tested with silver nitrate. Return the filter paper and residue to the crucible. Dry in an oven at 110°C for overnight and cool and weigh.

C3- Calculation

Ash insoluble in dilute HCl (on dry basis) = 100 x (M2 - M)________________

M l -M

Where:
M 2 = mass of dish with acid insoluble ash plus filter paper
M = mass of empty crucible plus filter paper
M l = mass of crucible with the dried sample

ANNEX-D
DETERMINATION OF TOTAL PROTEIN (KJELDAHL METHOD)

D1- Reagents
D1.1 Kjeldahl catalyst: - 15gm Pot. Sulphate + 0.5gm Copper sulphate
D1.2 Sulphuric Acid - Concentrated
D1.3 NaOH solution- 50% (1+1). Let stand until clear
D1.4 Standard NaOHsolution-0.1 N=0.1 M (4.00gm/litre)
D1.5 Standard acid solution- Prepare either HCl or H2SO4 solution HCl sol-0.1 N= 0.1 M (3.646gm/litre)
D1.6 H2SO4 sol - 0.1N=0.05 M (4.9gm/litre)
D1.7 Methyl Red Indicator - 0.5gm in 100ml absolute ethanol

D2- Procedure

Weigh 1-1.5 g of prepared sample and transfer to a Kjeldahl digestion flask. Add 15 g of potassium sulphate, 0.5 g of copper sulphate and 15 (use an exact amount) ml of sulphuric acid with one or two boiling chips. Heat the flask gently in an inclined position until froathing ceases then boil briskly for 2 hours. Allow to cool. Add approx 200ml of water and 25ml of sodium thiosulphate solution (80g/L) and mix. Add a piece of granulated zinc or anti bump granules and carefully pour down the side of the flask sufficient sodium hydroxide sol (1+1) to make the contents strongly alkaline (about 110ml). Before mixing the acid and alkaline layers connect the flask to a distillation apparatus incorporating an efficient splash head and condenser. To the condenser, fit a delivery tube which submerges just below the surface of acid solution in a receiving flask and boil until about 150ml of the distillate is collected. Add 5 drops of methyl red indicator and titrate with 0.1N NaOH. Carry out a blank, 1 ml of 0.1 HCl or H2SO4 is equivalent to 0.0014 of N.

% N = [(ml std acid x N of acid – ml blank x N of base) – (ml std base x N of base) x 1.4007]/ sample weight in g

Total protein = N X 6.25

ANNEX-E
DETERMINATION OF TOTAL VOLATILE BASE NITROGEN

E1 Apparatus
E1.1 Laboratory blender (you don't need a meat grinder nor homogenizer for PRAHOC. Blender is enough)
E1.2 Burette, 5 ml, graduated to 0.01 ml
E1.4 Fluted filter, 150 mm, for fast filtering
E1.5 Steam distillation apparatus (see Figure 3 for a diagram of the apparatus)

E2 Reagents

E2.1 Perchloric acid solution, 6 g/100 ml
E2.2 Sodium hydroxide solution, 20 g/100 ml
E2.3 Hydrochloric acid standard solution, 0.05 N, or 0.01 N if an automatic distillation/titration system is used
E2.4 Boric acid solution, 3 g/100 ml
E2.5 Silicone anti-foaming agent
E2.6 Phenolphthalein solution, 1 g/100 ml in 95% ethanol
E2.7 Tashiro's indicator solution: 0.2 g methyl red and 0.1 g methylene blue in 100 ml 95% ethanol

E3 Procedure

The sample should be finely homogenized using a blender. 10 g (±0.1 g) is weighed into the container of a blender, 90 ml of perchloric acid solution (6 g/100 ml water) is added and the sample homogenized for 2 min. The sample is then filtered through a fluted paper or under vacuum. At this stage, the sample solution is stable and can be kept refrigerated (2–6°C) for a week or so.

50 ml of the prepared extract is transferred to a steam distillation apparatus, together with a few drops of phenolphthalein solution (1 g/100 ml 95% ethanol), a few drops of silicone anti-foaming agent and 6.5 ml of sodium hydroxide solution (20 g/100 ml water). Steam distillation is immediately commenced and 100 ml of distillate is collected.

The distillation tube is submerged in a 100 ml solution of boric acid contained in a conical flask and to which 2–3 drops of Tashiro's indicator solution have been added. Distillation is continued for a total of 10 min after which the distillation tube is removed and washed with water, all rinsings are retained in the receiver flask.

The distillate is titrated with standard hydrochloric acid solution (manually or using an automated distillation/titration apparatus). The TVBN concentration is calculated as:

TVBN (expressed as mg/100 g of sample) = ((*V*1 – *V*0) × 0.14 × 2 × 100)/*M*

Where:
*V*1 = volume of 0.01 ml mol hydrochloric acid solution in ml for sample,
*V*0 = volume of 0.01 ml mol hydrochloric acid solution in ml for blank, and
M = weight of sample in g.

The blank sample is prepared by adding 50 ml of the perchloric acid reagent to the steam distillation unit instead of 50 ml of the sample extract and repeating the steps above.

Quality *Assurance*:

Duplicate analysis should normally be performed with the difference between duplicates being no greater than 2 mg/100 g.

The apparatus and procedure can be checked by distilling solutions of ammonium chloride equivalent to 50 mg TVBN/100 g.

Demonstration of Sustainable Seaweed Culture and Processing in Aceh, Indonesia and the Philippines - Opportunities for Women to Improve Household Welfare

Food Safety and Value-Added Product Development/Activity/09FSV02NC

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ABSTRACT

This project works with the local community to develop a more sustainable use of tambaks, other than the mono-culture of shrimp that was the norm before the 2004 tsunami. The use of polyculture and production of seaweeds were suggested as more sustainable aquatic farming methods. The project was conducted in collaboration with colleagues from the Philippines who had considerable experience with seaweed production, processing and marketing. A series of workshops were conducted to train the women and men who work together in the ponds to care for the seaweeds or in the case of the Philippines, how to culture seaweed in coastal environments. Another series of workshops focused on the women in the communities and teaching them recipes and preparation methods for using seaweeds and seaweed products in their family food supply.

The farmers have been very successful, with new cash crops of seaweed and soft shell crabs to go along with improved growth and survival of shrimp from the polyculture as well as improved water quality. The women from the training course workshops have learned several recipes for using seaweeds as vegetables and in snack foods. They also learned how to extract agar, which can then be used as a thickener or to make candies and desserts. Finally, farmers were aided in the construction of drying platforms that vastly improves the quality of dried seaweed and reduces contamination with sand and shell from drying on the ground. A commercial seaweed buyer has committed to purchasing 14 MT a month and is supplying baling equipment and additional tables. The success of the project was further underscored by the commitment of the government of Indonesia to provide funds for further development of seaweed culture in additional communities in Aceh province.

INTRODUCTION

Scientists from the Philippines have been leaders in the development of red algae harvesting, culture, domestication, and processing into marketable products (Hurtado 2002; Santelices and Doty 1989). This proposed activity was built largely upon the successful transfer of technology from the SEAFDEC in the

Philippines to other regions of the Philippines and the Aceh Province of Indonesia. Women were the primary beneficiaries of the earlier training in the Philippines and Indonesia. This was continued in this phase with repeated workshops for women. In fact, many of the world's leaders in seaweed culture are women, and women conduct many of the culture and processing activities. The farmers in Aceh, mostly women, specifically requested that additional training be provided from the experts in the Philippines to further develop the potential for seaweed production, processing and utilization for various products.

The technical and environmental benefits of polyculture of seaweeds in shrimp and fish ponds are well documented (Ryder et al. 2004a,b; Marinho-Soriano et al. 2002; Nelson et al. 2001; Neori et al. 2000). Polyculture of seaweeds in shrimp and fish ponds has proven popular in several coastal communities based on our current AquaFish CRSP. Large volumes of *Gracilaria* and *Eucheuma spp.* are produced in ponds with small volumes being used for home consumption as fresh sea vegetables or for agar for cooking. However, more seaweed is being produced than is needed for home use. Farmers need assistance to learn how to handle and process their raw seaweed into more valuable semi-processed forms that will be of interest to commercial agar buyers. Additionally, training of women on cooking and preparations of seaweeds for the kitchen would be beneficial to enhance household seaweed consumption and health.

Demand is significant for agar based candy and desserts in Indonesia and the Philippines. However, a suitable grade of agar is needed before it can be made into a marketable candy. The pharmaceutical grade agar used in microbiology demands a yet higher grade. In both cases, contamination and spoilage are the primary reasons for degradation. With the guidance of researchers and extension specialists, farmers have developed a method of off the ground drying on racks. The racks were constructed of locally available components (lumber, bamboo, ropes, and fish nets) and serve to elevate the seaweed and facilitate manually turning the seaweeds. This serves to increase the rate of drying, thus reducing spoilage, and it reduces contamination from soil, shells, and rocks that occur when the seaweed is dried on the pond bank or coastal shoreline. We would like to demonstrate to farmers in Aceh and additional locations in the Philippines how the seaweed can be partially processed to increase its value as an industrial source of agar.

OBJECTIVES

1. Demonstrate and train women to recognize the many advantages of utilizing seaweeds to improve family nutrition and as a potential cottage industry to improve household and community wealth.
2. Conduct a series of workshops regarding proper harvesting, handling, and drying of red seaweeds.
3. Build demonstration seaweed drying racks in three communities.
4. Conduct workshops on methods of using seaweed agar to make candy and desserts.
5. Demonstrate methods to partially process seaweed to increase its value as an industrial supply of agar and carrageenan products.

RESULTS

The first workshop was conducted by Ms. May Myat Noe Lwin and Hasanuddin from January 15-18, 2010. The subjects included polyculture of soft-shell crabs and seaweeds in shrimp ponds. This workshop, and two subsequent workshops in May, 2010 were added at the request of our partners at Ujung Batee as they had several farmers interested in soft shell crab production in polyculture with shrimp and seaweeds. The opportunity to incorporate an additional female scientist/farmer who was based close to Aceh was also a benefit to the project. These workshops, which were in slightly different locales, still including seaweed and agar content, but had a greater focus on soft shell crab in response to the local request. In April 2010, Fitzsimmons traveled to Banda Aceh to review seaweed and shrimp polyculture efforts. During meetings with Hasanuddin, Coco, Sarapuddin and Samsul, progress was reviewed and plans discussed for efforts under the new phase of the AquaFish CRSP project. We traveled to Pidie for

Ms. Lwin with January 2010 Workshop

Farmers with seaweed drying on pond bank bankApril 2010

on -site workshop and review of seaweed culture in shrimp ponds and to meet with farm families. Opportunities for Saudi scientists to visit Aceh who are interested in the polyculture technique were discussed. Fitzsimmons also met with Hasanuddin's MS advisor at local university and agreed to serve on graduate committee. Finally, we made plans for graduate student Sidrotun Naim to visit Aceh in August 2010.

During May 5-10, Ms. Lwin made another trip to Aceh to conduct additional workshops with Hasanuddin, Sarapuddin, and Samsul to expand upon the soft-shell crab and seaweed polyculture in shrimp ponds. In August 2010, Upton Hatch from North Carolina State University and Sidrotun Naim (Graduate student from Arizona) met in Banda Aceh to conduct interviews with farmers and Ujung Batee staff to evaluate the impacts of seaweed culture as part of the integrated polyculture system promoted to the former shrimp farmers in the region. Additional interviews were conducted by Dr. Hatch in August 2011 associated with project 09SFT06NC. The evaluation and results of the initial visit are part of the submitted trip report and recommendations included some of the activities outlined in this investigation. Overall, the report concludes that seaweed polyculture has an excellent opportunity to be incorporated into and provide several important benefits to the existing aquaculture system. However, some marketing and production constraints needed to be addressed before the potential can be fully realized. This included additional training on handling and drying seaweeds. Training workshops regarding proper harvesting, handling, and drying of red seaweeds for the region were planned and implemented in response to these recommendations. As this was considered to be a high priority, we scheduled this training to occur in conjunction with the agar as candy and cooking ingredient workshop. An additional recommendation was that financial support for purchase of drying racks for farmers who have had successful harvests using seaweed polyculture system would be useful. Although demonstration-drying racks for seaweed have been built through this project, additional, larger units will be required to produce the quantities of seaweed needed for wholesale distribution. Other recommendations suggest: 1) market opportunities be improved through establishment of certification process and facilitation of selling seaweed through forward contracting between farmer and production plant; 2) support for applied research and extension on understanding the relationship between white spot virus and other crops in polyculture system (tilapia, milkfish, and seaweed); and, 3) support for applied research and extension on understanding the relationship between odor and crops in polyculture systems (tilapia, shrimp, milkfish, and seaweed).

Largely based on AquaFish activities on the training and implementation of shrimp/finfish-seaweed polyculture in various communities of Aceh Indonesia (Pidie Jaya, Aceh Utara, Aceh Timur and Lhok Seumawe), the Central Government under the Directorate General Aquaculture is now interested in funding farmers to expand seaweed polyculture in the Aceh province of Indonesia. Following our preliminary surveys we have identified several opportunities to improve the success of *Gracilaria* culture in Aceh and the livelihood of its farmers. This includes building a market link for seaweed to include surveys of buyers in Indonesia, training farmers on seaweed drying, building a centralized seaweed processing center, providing key extension personnel and/or farmers some training in seaweed culture in Indonesian provinces (*i.e.* Sulawesi) where seaweed farming and marketing are more established, and identifying the potential problems some farmers perceive in culturing milkfish with seaweed relative to the success of shrimp-seaweed polyculture.

A series of workshops were held in July 2011 to further demonstrate seaweed culture and more importantly demonstrate drying and handling procedures in Aceh, Indonesia. Each of the local shrimp farmers typically have <1-hectare ponds (tambak) that they operate as the main source of income for the family. Most of the farmers have adopted the polyculture of *Gracilaria* seaweed in the ponds as we had recommended last summer. Many of the ponds have luxuriant growth of seaweed and improved survival and growth of the shrimp. However, their initial attempts to sell the seaweed to professional buyers had failed. The farmers had pulled the seaweed from the ponds and were drying it on the pond banks. The seaweed was contaminated with sand and snail shells and the bottoms of the piles was decomposing rather than drying properly. For the July workshops, our partners at Ujung Batee suggested we utilize the central school location at Sigli rather than try to hold three separate workshops. So, rather than workshops in Meuraksa, Lancang and Krueng, we held the consolidated workshops as the Sigli school. A major portion of the July 25 presentations prepared by Maria Luhan and Evelyn G. de Jesus-Ayson included discussions on the reasons that the seaweed for processing had to be dried properly and kept uncontaminated. They also described how to build sturdy tables of local materials for drying large quantities of seaweed and how the product would be further processed to make pharmaceutical grade agar (carraganeen).

Completion of first drying

Drying seaweed on table rather than pond

On July 26 we held a second workshop. In this workshop, Maria and Evelyn focused on home uses of *Gracilaria* and other seaweeds. They provided several translated recipes from the Hawaii Sea Grant publication "The Limu Eater: A Cookbook of Hawaiian Seaweed" (Fortner 1978) to participants who then broke up into three groups where each prepared a different product. The first group took finely chopped fresh *Gracilaria*, mixed it with wheat based flour and seasonings with a little water. A small ball of dough was then flattened through a tortilla type press. The resulting chip was then deep fried in

A confident seaweed chef

School kids learning about nutritious seaweeds

Women learning to cook seaweed dishes

Women attending second day of seaweed workshops

oil to make a seaweed flavored chip. The second group lightly cooked the seaweed (blanched) and then prepared a casserole style meal with onions, carrots, potatoes, tomatoes, and some local vegetables we did not recognize. The third group boiled their seaweed and then strained it through tightly twisted cheesecloth and collected the raw agar. The agar is then frozen and thawed and allowed to separate. This partly processed agar is commonly used for cooking as a thickener or as the main ingredient in several kinds of candy.

On July 28 a third workshop was held in Medan, with the team from Ujung Batee, several of the farmers and a seaweed buyer, Mr. Zarkasyi Bin Ismail, Drs. Hatch and DJ Ayson, and Maria Luhan. The workshop centered on values of products and on additional contributions from the seaweed buyer. The conclusions were that the buyer would loan money to the farmers to build four additional tables, beyond the tables AquaFish CRSP had sponsored. The farmers would repay the loan in quarters taken from their first four shipments of dried seaweed. The intent is to supply 600 MT per month from the Sigli farmers at a price of 3,500 rupiahs per kg.

A November report from Hasanuddin documents that farmers have now distributed 30 tons of seedling seaweed material to many other village farming areas (Kuala Simpang district, Lhok Seumawe district, Biruen district, Batee village and other villages around Pidie) as part of the effort to meet the 600 MT per month target. The Sigli farms are also harvesting 2 MT per week themselves.

In December 2011, Fitzsimmons returned to Aceh to lead a small workshop to review progress and discuss the operation and construction of additional drying tables that were being used in Sigli. The new tables were constructed with plastic netting rather than bamboo slats as in the Filipino model first built. The tables used a multiple layer array that the farmers felt could dry more effectively by stacking thin layers of seaweed and then rotating the stacks. Four of these new styles had been built and installed at the ponds. The farmers decided they preferred to have the drying tables at the ponds rather than carrying wet seaweed to the homes, although this requires them to run out to the ponds to cover the seaweed during rain events.

The farmers also decided to test another style of production we had suggested. Line culture is more intensive. However, the buyers were complaining of contamination from the bottom culture and several of the farmers decided to try this system we had described before. So far the results are encouraging and the farmers report the shrimp still crawl around the suspended seaweed and graze on epiphyton.

New style of drying table

Line style culture of seaweed

Overall the mission was very productive. The farmers are on the verge of having a significant new revenue stream that comes entirely from a by-product of improving pond water quality. Evelyn Ayson and Maria Luhan had a great rapport with the women of Sigli. The women of the community have a new highly nutritious aquatic vegetable to prepare in several recipes. And they understand how to process the seaweed to generate agar for use as a thickening agent in cooking or as a base for making candies and desserts.

Dr. Borski visited SEAFDEC in the Philippines in December 2010 to discuss the implementation of seaweed culture workshops including seaweed drying and processing to agar. A workshop on “Small-scale Aquaculture and Livelihood Ventures: Seaweed Culture” was conducted in February 2011 in Roxas City in the province of Capiz on Panay Island (Visayas region) in the Philippines. This followed two other workshops conducted in January 2011 in two communities in Antique, Iloilo, one of the poorest provinces in Visayas region of the Philippines, that was coordinated with integrated culture of milkfish. Another workshop was held in Puerto Princessa, Palawan, Philippines in December 2011. These workshops provided training in seaweed culture, construction of rafts for coastal seaweed culture, seaweed processing for production of agar, and methods for pickling seaweed and making seaweed foods (crackers, tortillas) as a value-added nutritional product and income opportunity for households, whereby food products could be sold at local markets. The workshops in Roxas City and Puerto Princessa included the training of 42 women on value-added seaweed processing and nutrition. Overall, the workshops supported development of seaweed culture and processing, and for production of foods that can improve household nutrition and income opportunities in much needed areas of the Philippines. Participants were enthusiastic and appreciative of the training received.

CONCLUSIONS

We are very pleased to see that the project appears to be headed to even greater success. We succeeded in conducting all of our workshops with even more attendees than we had hoped. The workshops targeted toward women were especially successful when our Filipino and/or Thai colleagues led the teaching efforts. The women in Pidie and Sigli regions of Aceh Indonesia and in the Panay and Palawan regions of the Philippines who have received training on the practical uses of seaweed and agar in the kitchen are beginning to use them in cooking and agar preparation. These foods that can also be sold at local markets for added income opportunities. The production and polyculture aspects have been widely accepted by farmers in the Aceh region. The farmers report improved growth and survival with seaweeds growing in the ponds. The farmers have the three drying tables completed and are now using them to meet the quality requirements of the professional buyers. The commercial seaweed buyer supplied additional tables and a baler and firm orders for 14 tons of dry seaweed have been placed. In the Philippines, fisherfolks learned how to grow seaweed in ponds as well as marine coastal habitats.

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Assessing the Impacts of Sustainable Freshwater Aquaculture and Small-Sized/Low-Value Fisheries Management in the Lower Mekong Basin Region of Cambodia and Vietnam

Food Safety and Value-Added Product Development/Study/09FSV03UC

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INTRODUCTION

Objective: The objective of this study is assess and demonstrate the impact of the investigations in the AquaFish CRSP project "Development of alternatives to the use of freshwater low value fish for aquaculture in the lower Mekong basin of Cambodia and Vietnam: implications for livelihoods, production and markets" on both the private and public sectors and on food security, poverty alleviation, economies, and resource management policies of Cambodia and Vietnam.

Significance: In the Mekong region, many capture fisheries resources have been largely overexploited and, as a result, development of aquaculture has been encouraged to provide the protein, income, employment and export earnings for some countries. Such a development trend implies that sufficient feed for aquaculture production will be available. One source of feed is low value/trash fish (Low value/trash is defined as fish that have a low commercial value by virtue of their low quality, small size or low consumer preference). There is increasing demand and trade in the lower Mekong region of Cambodia and Vietnam for low value/trash fish for (1) local consumption (e.g. fresh, dried); (2) direct feed (e.g. livestock, high value species aquaculture); (3) fish meal production (e.g. poultry, aquaculture); and (4) value-added products (e.g. fish sauce, fermented fish, fish paste, smoked fish).

There is an increasing conflict between the use of small-sized/low value fish for animals/fish and for human consumption. Supplies of small-sized/low value fish are finite, and as indicated by a recent increase in price, i.e. demand is outstripping supply. Small-sized/low value fish are important to the communities and aquaculture, as well as the ecosystems in Cambodia and Vietnam. There is a need to support the development of a policy and management framework to address aquaculture and capture fisheries interactions.

This research project will produce a number of outcomes, including development of a plant based feed for snakehead fish, recommendations to government and the private sector for a sustainable snakehead aquaculture industry, value-added products from small-sized/low value fish such as fish paste and fish sauce, extension/outreach technologies, recommendations for improvements in the marketing system for both capture and culture fish in the region, and recommended policies to improve management of small-sized/low value fish in the Mekong area. These outcomes will impact both the private and public sectors through improvements in technologies, commercialization of new products, sustainable aquatic resource management practices, and policies for aquaculture and capture fisheries. It is expected that the outcomes will have an impact on improving food security, livelihoods, poverty and economic development in the region. Information is needed to demonstrate the importance of this research, the direct and indirect impacts of the research, the communication/dissemination of technologies, and human capacity development.

METHODS

Agricultural research generates many types of outputs. These include technologies embodied in a physical object (e.g., improved feed), management tools and practices, information, and improved human resources. Impact assessment is a process of measuring whether or not research has produced its intended effect—that of meeting development objectives, such as increases in production and income and improvements in the sustainability of production systems. It is important to demonstrate that the changes observed are due to a specific intervention and cannot be accounted for in any other way. The effects can be measured at the household, target population, national, and regional levels. Impact assessment to be undertaken in this investigation will be of two types: ex- post and concurrent. The ex-post assessment refers to the evaluation made upon the completion of a project to determine achievements and to estimate the impact of research. Returns to investment in research and development are typically assessed using the ex-post concept. These studies also help to understand the process of disseminating technology and the constraints to its adoption. Concurrent assessment or evaluation is done to identify the impediments for larger adoption of the research outputs. The purpose of a concurrent evaluation is to correct the gaps and provide feedback for refining and tuning the technology as per the stakeholders' requirements. Often it is known as constraint analysis. Four components determine the adoption of a technology: technology traits (e.g. duration, quality, etc.), policy environment (e.g. price support, procurement, etc.), institutional arrangements (e.g. seed supply sector, credit availability, etc.), and infrastructure (e.g. markets, roads, power, clean water, processing facilities, etc.). Determining constraints for larger adoption forms a part of the impact assessment. Such studies are characterized as part of the early impact assessment. These provide useful information on conditions for larger returns and benefits of research investment. As reported above, this project will produce a number of outcomes. This project will have direct, indirect, and intermediate impacts in the two countries. Direct impact refers to the impact on the welfare of people and the environment as a result of adopting a technology. It is reflected mainly as an increase in productivity, a reduction in per unit cost of production, and/or reduced pressure on expansion into fragile ecosystems because of improvement in technology. Indirect impact includes flow-on impacts to other activities. Intermediate impact refers to increases in the knowledge base that could subsequently have a direct impact.

Through this investigation, students and scientists will be trained in methods to undertake both ex-post and concurrent assessments. Students and scientists will be assigned to each of the six investigations in the project to undertake impact assessment. Impact assessment reports will be prepared and presented.

QUANTIFIED ANTICIPATED BENEFITS

- 12 undergraduate and graduate students in Cambodia and Vietnam will be trained and have experience in undertaking impact assessment of agricultural and resource management research.
- 12 scientists and academics in Cambodia and Vietnam will be trained and have experience in undertaking impact assessment of agricultural and resource management research.
- 10 provincial fisheries officers will be trained and have experience in undertaking impact assessment of agricultural and resource management research.

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RESULTS

Output 1: Impact Evaluation of Development Projects: Workshops

Conducted by: Dr. Boris E. Bravo-Ureta, Professor of Agricultural and Resources Economics, University of Connecticut

Trip Itinerary for Dr. Bravo-Ureta:
April 26 AM: Depart the US
April 27 PM: Arrive to Ho Chi Minh City and travel to Can Tho
April 28 AM: Arrive in Can Tho and initiate Workshop at Can Tho University in the PM (56 participants)
April 29: Workshop at Can Tho University AM and PM
April 30: Travel to Phnom Penh, Cambodia
May 1 and 2: Holiday
May 3 and 4: Workshop at IFReDI AM and PM (49 participants)
May 5: Travel to Hong Kong
May 6: Travel to Tokyo and on to the US

Workshop Goal: To train participants on impact evaluation (IE) concepts and methodologies so that they are able to design and conduct IE of aquaculture projects.

Workshop Outputs: Trained participants; Draft outline of the IE participants plan to undertake prepared.

Workshop Dates:
Cantho University, Viet Nam, April 28-29, 2011

Phnom Penh, Cambodia, IFReDI Meeting Hall, May 3-4, 2011

Workshop Outline:

DAY 1:
Project Cycle
Performance Indicators, Logical Framework and Results Matrix
Financial and Economic Evaluation of Projects
Financial Criteria for Evaluating Projects
The Basics of Impact Evaluation

DAY 2:
Alternatives Approaches to Impact Evaluation
Data for Impact Evaluation
Evaluation of MARENA: A Case Study

The Way Forward: Work on Teams

Workshop participant list: See Appendix 1

Workshop PowerPoint's: See Appendix 2

Output 2: Assessing the impacts of sustainable freshwater aquaculture development and small-sized/low-value fisheries management in the Lower Mekong basin region of Cambodia and Vietnam

So Nam and Robert Pomeroy

INTRODUCTION

In the Mekong region, many capture fisheries resources have been largely overexploited and, as a result, development of aquaculture has been encouraged to provide the protein, income, employment and export earnings for some countries. Such a development trend implies that sufficient feed for aquaculture production will be available. One source of feed is small-sized/low value fish (species that generally has a maximal total length of equal to or less than 25 cm and a low market value, generally 5 to 10 times lower a market value of big-sized or commercially important fish species) (So Nam et al., 2009a). There is increasing demand and trade in the lower Mekong region of Cambodia and Vietnam for small-sized/low value fish for (1) local consumption (e.g. fresh, dried); (2) direct feed (e.g. livestock, high value species aquaculture); (3) fish meal production (e.g. poultry, aquaculture); and (4) value-added products (e.g. fish sauce, fermented fish, fish paste, smoked fish), which lead to the increase in price over the last decade and the predicted increase in price over the next few years (So Nam & Pomeroy, 2011). Prices also fluctuate with the demand for fish meal in the livestock and aquaculture industry and the availability of raw materials for fish meal production in the Lower Mekong basin (So Nam et al. 2009b; Le Xuan Sinh and Pomeroy, 2009; So Nam et al., 2007; So Nam et al., 2005). Given that aquaculture is predicted to grow while capture fisheries remain stable, it will become increasingly more difficult to meet the demand for small-sized/low value fish for human consumptions.

There is an increasing conflict between the use of small-sized/low value fish for animals/fish and for human consumption in the Lower Mekong River basin (Hap Navy and Pomeroy, 2009). Supplies of small-sized/low value fish are finite, and as indicated by a recent increase in price, i.e. demand is outstripping supply, due to mainly depletion of fish stocks resulting from overfishing, population growth and ecosystem degradation (So Nam et al., 2009a; Le Xuan Sinh and Pomeroy, 2009). It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products, etc (Un Sophea et al., 2010; So Nam et al., 2009b; So Nam et al., 2009c). Proponents of this suggest small-sized/low value fish as food for poor domestic consumers is more appropriate than supplying fish meal plants for an export income oriented aquaculture industry, producing high value commodities (Le Xuan Sinh and Pomeroy, 2009). On the other hand, food security can also be increased by improving the income generation abilities of poor people, and it can be argued that the large number of people employed in both fishing and aquaculture has this beneficial effect, via income generation, rather than direct food supply.

The government of Cambodia put a ban on snakehead farming in May 2005 and the reasons for this was the potential negative impacts on wild fish populations from wasteful snakehead seed collection and on other fish species diversity, and also potential negative effects on poor consumer groups from decreased availability of small-sized/low valued fish (So Nam et al., 2007). After the ban on snakehead culture in

Cambodia, snakeheads have illegally been imported from the neighboring countries, particularly from Vietnam, to supply high local market demands in Cambodia. Furthermore, the first phase study funded by AquaFish CRSP (07MNE01UC) showed that freshwater small-sized fish have illegally been exported to Vietnam for feeding the significantly and commercially developed snakehead aquaculture in Vietnam and the incentives for choosing snakehead before other fish species by approx. 20,000 fish farmers are strong as it generates more than 10 times higher profits than other fish species (So Nam et al., 2009a). Therefore, the ban does not only result in positive impacts on poor consumer groups from increased availability of freshwater small-sized fish in Cambodia, but also providing negative effects on livelihood of tens of thousands of snakehead farmers who depend on this livelihood for generating household income. In other words, these snakehead fish farmers have lost their important livelihoods and household income. Moreover, the ban also does not provide positive impacts on snakehead wild stocks as fishing pressure on wild snakehead using illegal and destructive fishing gears particularly electro-shockers has been increased for the recent years in order to supply local and external markets (So Nam et al., 2009a).

In Vietnam, snakehead fish have been domesticated for almost two decades in the Mekong Delta (So Nam, 2009). Aquaculture of this domesticated snakehead fish has commonly and wisely been practiced, and recently intensified by using freshwater and marine small-sized fish as direct feed. The snakehead aquaculture production increased from 30,000 ton in 2009 (Le Xuan Sinh and Do Minh Chung, 2009) to 40,000 ton in 2010 (Le Xuan Sinh, pers. comm., 2011). As a result, environmental issue and outbreak of fish disease are the biggest problems, which cause high fish mortality due to poor water quality, and cause decreased income of hundred thousands of snakehead farmers in the Mekong Delta in Vietnam. As intensive snakehead aquaculture has been developed, many kinds of pathogens may cause serious diseases.

The recent studies of AquaFish CRSP produced a number of outcomes, including development of a plant based feed for snakehead fish (Tran Thi Thanh Hien and Bengtson , 2009; Tran Thi Thanh Hien and Bengtson 2011), recommendations to government and the private sector for a sustainable snakehead aquaculture industry (Tran Thi Thanh Hien and Bengtson 2011, So Nam et al., 2011; Pham Minh Duc et al., 2011), value-added products from small-sized/low value fish such as fish paste and fish sauce (Kao Sochivi and Pomeroy, 2011; Un Sophea et al., 2010; So Nam et al., 2009bc) , extension/outreach technologies (Pham Minh Duc et al., 2011; So Nam et al., 2009a), recommendations for improvements in the marketing system for both capture and culture fish in the region (Le Xuan Sinh et al., 2011; Hap Navy et al., 2011; Un Sophea et al., 2010; So Nam et al., 2009c), and recommended policies to improve management of small-sized/low value fish in the Mekong area (So Nam & Pomeroy, 2011). These outcomes have impacted or are impacting both the private and public sectors through improvements in technologies, commercialization of new products, sustainable aquatic resource management practices, and policies for aquaculture and capture fisheries.

OBJECTIVE

The specific objective of this study is to assess the potential impacts of the two investigations: (1) 09IND02UC: Sustainable snakehead aquaculture development in the Lower Mekong River Basin of Cambodia and Vietnam and (2) 09MNE04UC: Developing management recommendations for freshwater small-sized/low value fish in the lower Mekong region of Cambodia and Vietnam. The impact assessment is the potential for (1) opening up the snakehead aquaculture again in Cambodia; (2) sustaining the development of snakehead aquaculture in Vietnam; (3) improving the management of small-sized fish in the Lower Mekong basin.

METHODOLOGY

This study was primarily a desk analysis of research findings, followed by a series of consultations and training workshops with all relevant government and non-government organizations, research and academic institutions, and the private sector on (1) Sustainable snakehead aquaculture development in the Lower Mekong River Basin of Cambodia and Vietnam; (2) Developing management recommendations for freshwater small-sized/low value fish in the Lower Mekong region of Cambodia and Vietnam; (3) Impact evaluation of development project in order to assess the potential impacts of the study.

RESULTS

Sustainable snakehead aquaculture development in the Lower Mekong River Basin of Cambodia and Vietnam
The three specific objectives: (1) to domesticate breeding of wild snakehead to address the snakehead banning issue in Cambodia in order to lift the ban on snakehead culture in Cambodia; (2) to study environment impacts, fish diseases and biosecurity of snakehead farming in Vietnam; and (3) to provide recommendations for policy and best practices development of snakehead farming were successfully addressed and achieved by the following summary of research findings.

In Cambodia, the present investigation demonstrated that 84 breeders of the wild striped snakehead Channa striata can successfully be developed, mature and semi-artificially induced spawning using HCG at doses of 1,000 $IU.kg^{-1}$ for female fish and 3,500 $IU.kg^{-1}$ for male fish at the hatchery of Freshwater Aquaculture Research and Development Center (FARDeC). The male fish receive 2-3 injections within 2-3 days before the female fish, which is received only 1 injection. With this optimal HCG doses, the spawning success is 100%; spawning time after the last injection of female and male fish is 9 hours; number of eggs spawned per kg female is 32,000; the fertilization rate is 87%; hatching rate is 73%; and the larval production and survival rate is 21,000 larvae per kg female and 72%, respectively.

The striped snakehead Channa straita aging 30 days old after hatch can gradually and successful accept formulated feed in replacement of small-sized fish in the rate of 10% every three days for a period of 30 days of feeding, and then be successfully grown out with a complete 40% crude protein pellet feed for a period of ten months to achieve a final weight of 314 $g.fish^{-1}$, a survival rate of 56%, and a FCR of 1.68. The F_1 broodstocks which can accept formulated or pellet feed are available for future domestication breeding and weaning at FARDeC. This has very important implications for protecting freshwater small-sized fish, which are usually fed to snakehead.

In the future, if the above technologies are successfully trialed in fields with snakehead farmers and widely adopted by snakehead farmers in Cambodia, there will be a great potential for opening up the snakehead aquaculture in Cambodia.

In Vietnam, The potential pathogens, including 32 genera of parasites, 4 genera of fungi and five genera of bacteria infesting snakehead fingerlings and grown-out snakehead in An Giang and Dong Thap provinces, Mekong delta of Vietnam are successfully identified, classified and documented.

In Vietnam, the main water quality parameters are successfully recorded in this study. The results of this study illustrated that temperature and pH value in snakehead cultured ponds in An Giang and Dong Thap provinces are not considerably varied. In the whole cultured period, the concentration of N-NH4+ and N-NO2- increases, while the concentration of N-NO3- reduces in the posterior end.

Improvement of snakehead culture skills is mostly from the gain of experiences and participation in trainings provided by provincial fisheries officers. Water quality management was applied by the majority of household (75%) such as the use of test kits. Most of the snakehead farming household (70%) complain parasite infection to their snakehead fish. Therefore, parasite infection is the key issue in snakehead farming in the Mekong Delta of Vietnam.

The potential pathogens, including parasites, fungi and bacteria infesting snakehead fingerlings and cultured snakehead in An Giang and Dong Thap provinces, Vietnam are successfully identified, classified and documented. Nine genera of parasites were identified from 142 samples of snakehead fingerlings in nursery ponds, including of Dactylogyrus, Trichodina, Epistylis, Trianchoratus, Chilodonella, Proteocephalus, Spinitectus, Pallisentis. Trichodina have the highest prevalence infection of 93.7%, while Proteocephalus and Henneguya had lowest prevalence infection of 3.52% and intensity of lowest (+). There were 23 genera of parasites identified from cultured snakehead sampled from growth-out ponds in An Giang and Dong Thap provinces. Of which, 6 new genera are found in cultured snakehead, comprising of Henneguya, Chilodonella, Epistylis, Tripartiella, Gnathostoma and Capillaria. Gyrodactylus is noted with the highest prevalence infection of 72.6% and the lowest is found in Lamproglena (0.7%).

Achlya sp. was isolated from snakehead fingerlings in nursery ponds in the first and second month of culture period. The frequency of appearance is 46% in the whole isolated fungi recorded. The optimum temperature for Achlya sp. VN1101 growth was 28oC. The results demonstrated that Achlya sp. VN1101 is main pathogen causing cotton-like in snakehead fingerlings revealed by pathogenicity experiment. There are 4 genera of fungi isolated from cultured snakehead in grow-out ponds in An Giang and Dong Thap provinces, including Acremonium (frequency of appearance is 35.7%), Geotrichum (28.6%), Achlya (21.4%) and Fusarium (14.3%). The fungi are recognized in the first three months of culture period, and Achlya is only noted in the first month of the cultured period when the fish is 96.6-165 g in weight.

81 bacterial strains are indentified from unhealthy fish. Bacterial strains are grouped to 5 genera based on morphological and biochemical characteristics, comprising of Aeromonas (frequency of appearance of 38.3%), Edwardsiella (17.3%), Vibrio (16.0%), Streptococcus (14.%) and Pseudomonas (13.6%). Of which, Edwardsiella was only isolated in the second month of the cultured period when fish was 175.7-295.3 g in weight, and Streptococcus was also detected in the fifth cultured month when fish was 620.4-850 g in weight. Besides, Aeromonas hydrophila was believed as a primary pathogen to snakehead fingerlings revealed by pathogenicity experiment. The clinical signs were observed, consisting of haemorrhage in fish body and fins, red spot in ventral area, and scales damage and loss.

Based the above research results an outreach document “Atlas of pathogens of the striped snakehead *Channa striata*” is developed and disseminated to all provincial fisheries extension officers and some snakehead fish farmers in An Giang, Dong Thap and Can Though provinces of the Mekong Delta, Vietnam for the purpose of reducing environment impact and outbreaks fish diseases, and for increasing biosecurity of snakehead farming.

The quantifiable economic benefits of this investigation are as follows:

- In Cambodia, approx. 20,000 farmers who used to produce 11,000 ton of snakehead will benefit from this Investigation by restarting their snakehead culture after the ban on snakehead culture in Cambodia by future adoption of breeding, weaning and growth-out technologies of snakehead fish developed by this investigation.
- In Vietnam, at least 30,000 farmers who are producing over 40,000 ton of snakehead will increase their fish production by increasing fish survival rate from 50% to 90% by future adoption of fish disease prevention and treatment proposed by this investigation
- The above research outputs have been informed to 40 scientists and researchers, 100 government fisheries officers/managers and policy makers, 50 aquaculture extension workers, 30 NGO staff, 20 aquaculture companies and 100 fish farmers working on snakehead aquaculture in Cambodia and Vietnam at the project inception workshops, final project stakeholder consultation

workshops, national aquaculture and fisheries symposiums, and aquaculture trainings for fish farmers in Cambodia and Vietnam.
- 500 copies of a Photo Atlas of pathogens of the striped snakehead *Channa striata* were disseminated to the above stakeholders.
- Six students, two in Cambodia and four in Vietnam, were supported by the project and graduated, and they are now working for private aquaculture companies and non-government organizations.
- More than 100,000 snakehead farmers in Vietnam will operate environmentally friendly, healthy and sustainable snakehead aquaculture after adoption of improved knowledge on fish health management and bio-security.
- At least 1,000,000 indirect beneficiaries in Cambodian and Vietnamese who consume snakehead fish in their protein diets.

Developing management recommendations for freshwater small-sized/low value fish in the Lower Mekong region of Cambodia and Vietnam

The objective of this study is to develop management recommendations for freshwater small-sized/low value fish in the Lower Mekong region of Cambodia and Vietnam in order to reestablish stocks to support food security and poverty alleviation.

This specific objective was achieved by the following management recommendations for sustaining small-sized fishery resources in the Lower Mekong basin.

1. The capture fisheries of Lower Mekong River basin in Cambodia and Vietnam are overfished due to illegal and high fishing pressures, population growth, and floodplain or wetland ecosystem degradation. Therefore the freshwater small-sized fish production, which contribute more than 80% to the total freshwater captured fisheries in the Lower Mekong River basin of Cambodia and Vietnam and are used and important for human food consumption, fish, including snakehead fish, and other animal feeds, and aquatic or wetland ecosystems, are scarce or limited, although the biodiversity of freshwater small-sized fish species is rich (at least 200 species). Capture fisheries are not the major threat to biodiversity in rivers – aquatic environmental or ecosystem degradation is.
2. Understanding the role of ecosystem variability (including hydrology) in sustaining the Lower Mekong's rich biodiversity is crucial. Development activities in a river system almost always result in the simplification, or even obliteration, of ecosystem diversity. These disturbances appear to be by far the greatest threat to sustaining aquatic biological resources in Lower Mekong River basin.
3. The important role that river floodplain fisheries play in maintaining aquatic biodiversity must be promoted more widely. All sectors should cooperate in integrated water resources management (i.e. IWRM approach).
4. The waters of the Mekong and its tributaries could be put to many uses: irrigated agriculture, potable domestic supply, hydroelectricity production, navigation and fisheries. In Cambodia, fisheries production is primarily from the wild capture fishery. Developments in other sectors will become increasingly common in the future and the wild fishery is likely to decline as a consequence. Actions to mitigate and manage the impacts of water management projects will minimize this decline; such actions depend upon an effective engagement of fisheries managers with planners in other sectors. Only through this approach can we have truly sustainable development for the people using the resources of the Mekong.
5. Emphasizing the importance of fisheries of small-sized fish species to livelihoods and food security provides the strongest and most relevant argument for improved management of the aquatic environment.
6. Fisheries activities can have negative impacts upon biodiversity. Improved management of law and regulation enforcement, and exploitation, by moderation the use of unsustainable fishing practices such electro fishing, small mesh size net fishing, brush-park fishing and pumping fishing method,

should centre on the promotion of co-management approaches to decentralization of fisheries management (i.e. dialogue between local resource users, government authorities, scientists and other stakeholders on management needs and methods in order to reduce the impacts of illegal fishing and overfishing.

7. Management initiatives need to be prioritized and adaptive, focusing on those species and habitats under greatest threat and basing on scientific research and monitoring data and local ecological knowledge. Recent experience has shown a high level of agreement between local ecological knowledge and fisheries science.
8. The use of local ecological knowledge as both a research tool and a mechanism for improving participation in management should be promoted more widely. There should be increased recognition of the importance of this knowledge base for biodiversity-related subjects.
9. The fishing "lot" system of floodplain fisheries and river dai fishery in Cambodia should be properly and scientifically evaluated to determine if it is an effective tool for sustaining biodiversity. Studies should include consideration of whether social equity and sustaining biodiversity are necessarily mutually exclusive. There is considerable interest internationally in this system as a way of improving environmental management.
10. Freshwater fish protected areas, dry season refuge ponds, and channel for migrating fish on floodplains should be maintained or scientifically identified and established in fishing “lot” areas, community fisheries areas, and floodplain rice-fields, and an adaptive plan for managing these protected areas should be developed and implemented to protect and enhance stocks or populations of this rich biodiversity.
11. Development planning should recognize the value of fisheries and their importance in the livelihoods of Cambodian and Vietnamese people.
12. Environmental Impact Assessments should consider all options for development, as well as the costs and benefits of competing uses of water.
13. Plans for water management projects should include consideration of sustaining, and where possible, increasing fish production.
14. The main elements of the flooding cycle and important fish habitats should be maintained where possible; if water management projects are designed to reduce flood levels then the consequences for fisheries production should be appraised and appropriate substitutes for livelihoods and income for those affected should be available.
15. Any evaluation of dams proposed for the Mekong mainstream and major tributaries should consider the consequences for fish migrations and floodplain production downstream, and should recognize that impacts could not be fully mitigated.
16. Mitigation measures should be incorporated in the design and operation of dams, including low-level weirs; these could include fish passes, maintenance of riparian flows, re-regulation of discharges and measures to improve water quality.
17. Dialogue should be maintained between LMB countries on mitigating transboundary impacts from water management projects, fishing activities and exotic species, both up-and downstream of Cambodia and Vietnam. Where migration routes cross national borders, fish stock management becomes a trans-boundary issue and requires international collaboration.
18. The emphasis might be on developing appropriate procedures for cooperation at the international level in harmony with national and local management initiatives. The best opportunities are with the high profile migratory fish species and the vulnerable habitats such as the flooded forests and the deep pools where a consensus already exists on the need for action.
19. More information is required on the ecology (e.g. migration and spawning sites and behaviors), population genetics (e.g. stocks), and value and importance for livelihoods of the Lower Mekong River fisheries of Cambodia and Vietnam. But enough is known to provide clear directions for management of theses freshwater fisheries. It is time to adopt an integrated approach to conserving and enhancing fisheries for the continuing well-being of Cambodia and Vietnam and their neighboring countries.

20. Macro-habitat requirements are known for a few species in broad categories such as floodplain habitats and deep pools. However, micro-habitat requirements are unknown for most species. For example, even if it is known that a certain species lives in deep pool habitats during the dry season, the habitat features that the species require within the deep pool (type of substrate, vegetation, depth, slopes, current etc.) are unknown. Such micro-habitat requirements determine types of pools certain fishes prefer and indirectly determine other ecological characteristics including migration patterns.
21. Feeding biology for most species is related to the micro-habitat issue since availability of food (for example on the floodplain) determines the preferred floodplain micro-habitat.
22. A more attainable short-term goal is to promote changes to land classification systems, which are the basis for both natural resources planning and asset allocation. The current system suffers from a bias toward dry-season agricultural uses of land. It appears that legal systems are ill equipped to deal with assets undergoing dynamic changes especially for seasonal wetlands. Wetlands rarely have any legal status and are usually regarded as open access areas during the flood season. Converting these areas to agricultural use would not necessarily be more efficient biologically but it would enhance people's security of access and ownership. The legal status of wetlands and related institutional limitations are already recognized as constraints in achieving sustainability of fisheries and other natural resources.
23. Aquaculture production, including snakehead fish over nearly past ten years in Cambodia and Vietnam has rapidly expanded and continued expansion of aquaculture will contribute significantly to meeting the anticipated demand for fish products in the coming decades, although the difficulties in meeting anticipated demand are considerable.
24. Aquaculture, capture fisheries and reservoir management should be considered as a holistic system. Concentrating policy and development efforts towards aquaculture, as an 'easy option' for fish production, without taking proper care of the wild fisheries could result in a dramatic loss of wild fisheries resources, with food security implications for the Lower Mekong Basin of Cambodia and Vietnam, particularly for poor people. Similarly, aquaculture and fisheries are strongly influenced by the development of other sectors. A balanced approach to fisheries development is required.
25. Aquaculture can have the greatest impact on rural households in areas with food insecurity and limited wild fish supplies. The approach to supporting food security and livelihoods should be based on identifying these areas and supporting local area development, which may be aquaculture or wild fisheries activities or a combination of both. Therefore establishment and implementation of an action plan for development of aquaculture of indigenous Mekong fish species, including genetic knowledge and information, which are less dependent on freshwater small-sized fish as direct feed (e.g. omnivorous and herbivorous fish species), should be encouraged and supported by public and private sector and non government or civil society organizations.
26. Further research and development of formulated diets and domestication breeding, weaning and growth-out technologies for sustaining snakehead aquaculture in Cambodia and Vietnam should be a joint effort and support among public and private sectors, research and academic institutions, non-government organizations and snakehead farmers. The demand of freshwater small-sized fish is outstripping supply, so these fish should be important for local communities' food consumption and for maintaining aquatic biodiversity and ecosystems.
27. Golden snails are so abundant in all rice fields of the Mekong Delta and harmful to rice production. Research on snakehead aquaculture using golden snails as a source of protein should be encourages and supported. This will have very important implications for reducing environmental and economical impacts caused by golden snails.
28. There are several constraints to sustainable development of snakehead aquaculture, especially in Cambodia, that will have to be addressed. Many of these are institutional rather than technical. The existing capacity and resources of government institutions for participatory extension and research is relatively weak and manpower is limited. Therefore, capacity building is required to support this approach. New partnerships going beyond traditional aquaculture extension are needed. The policies to support an integrated approach to aquaculture are not yet in place. There is a need to develop enabling policies to support the approach, but this will take time.

29. Diversification of rice farming systems using omnivorous or herbivorous indigenous Mekong fish species and integrated pest management, including economics and livelihood impacts of farming options and practices.
30. Reducing risks to rural livelihoods from aquatic animal diseases is one of the priority areas for sustaining snakehead aquaculture in Cambodia and Vietnam.
31. An efficient low-cost contingency plan for fish health management may also be established on a catchment as well as transboundary basis. Plans should be prepared for the containment and treatment of fish disease including the prevention of trade in live fish and movement of fry, fingerlings and breeders from a catchment area or cross border or transboundary area where an outbreak has been detected.
32. Further maximization of the utilization of freshwater small-sized fish for human Consumption through improving quality standard and safety with appropriate value added product development (e.g. fermented fish paste in Cambodia and fish sauce in Vietnam).
33. More information is needed on the trade of freshwater small-size fish and fish products, including snakehead fish within the basin and exports and imports to and from the basin.

POTENTIAL IMPACT ASSESSMENT

Based the above summary of research findings, in Cambodia, after the snakehead ban, Approx. 20,000 households utilized 55,000 ton of small-sized freshwater fish as feed to produce 11,000 ton of snakehead and earned a total income of US$ 22 million per year or an average of US$ 1,100/household/year lost their job and income. If future adoption of breeding, weaning and growth-out technologies of snakehead fish using formulated feed developed by this investigation is taken, (1) these 20,000 snakehead culture households can restart this business and earn this income; (2) 55,000 ton of small-sized freshwater fish can be utilized for human consumption as these farmers will utilize formulated diets for snakehead farming leading to improvement of water quality and biosecurity in snakehead farms for not only in Cambodia but also in Vietnam; (3) Approx. 16 million of wild collected fingerling can be wildly grown to breeder stage for the sustainable development and conservation of wild stocks of snakehead fish due to the dependence on hatchery snakehead fingerling of at least 16 million per year to produce the same production level of 11,000 ton as in 2004/05, before the ban on snakehead culture in Cambodia; and (4) fishing pressures on freshwater small-sized fish will decrease, and implications for sustainable utilization and management of these invaluable resources if the above management recommendations for freshwater small-sized/low value fish in the Lower Mekong region of Cambodia and Vietnam are implemented.

Based on the above summary of research findings, in Vietnam, snakehead farmers produced 40,000 ton of snakehead in 2010 by using approx. 30,000 ton of freshwater small-sized fish, 105,000 ton of marine small-sized fish and 45,000 ton of fish wastes from Pangasius fillet processing plants, with the survival rate of 40%-50%. If the farmers in the Mekong Delta of Vietnam potentially adopt the growth out technology of snakehead by using formulated diets and apply for good fish health management and biosecurity practices, the survival rate will increase up to 90%, leading an increase of snakehead production from 40,000 ton to 72,000-90,000 ton. Therefore the income of every snakehead farming household will be increased by 40-50%. Finally 30,000 ton of freshwater small-sized fish can be used for human consumption, implying for an increase in food security for the rural poor.

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Output 3: Trip Report for Snakehead study in Vietnam (May 28, 2011 - August 4, 2011)

Justin Grimm-Greenblatt[2]

I chose to conduct my research project in Can Tho University in Can Tho, Vietnam. This opportunity was provided to me through support from Robert Pomeroy PhD., Dorothy Goodwin International Experience Fund, and AquaFish CRSP. The research I was involved in was part of a larger project called AquaFish Collaborative Research Support Project (CRSP). It is currently being conducted in collaboration with the University of Connecticut (USA), Inland Fisheries Research and Development (Cambodia), and Can Tho University (Vietnam) and with the respective lead investigators Robert Pomeroy, So Nam (Cambodia), and Le Xuan Sinh and Tran Thi Thanh Hein (Vietnam). The objectives the project is as follows:

1. To domesticate wild snakehead to address the snakehead banning issue in Cambodia in order to lift the ban on snakehead culture in Cambodia
2. To study environment impacts, fish disease and biosecurity of snakehead farming in Vietnam
3. To provide recommendations for policy and best practices development of snakehead farming.

The project focuses on both the aquaculture of carnivorous fish and the management of lower value/trash fish by addressing the uses and bio-ecological characteristics of low value/trash fish and exploring alternative feeds and feed technology for freshwater aquaculture. By understanding the social, economic, and environmental/natural resource needs and implications of freshwater aquaculture, this project hopes to create sustainable freshwater aquaculture development in the Lower MKD of Cambodia and Vietnam. This project takes into account capture and culture fisheries and how they play a significant role in food security, poverty alleviation, and economies

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within Cambodia and Vietnam. It also addresses the combined management of capture and culture fisheries and the competition and conflict that has been increasing between the uses of low value/trash fish for feed and human consumption. The first phase of this project has already accomplished developing weaning methods so small, hatchery-reared snakehead can quickly adapt to pelleted diets; it was determined that snakehead survive as well on pelleted diets that have as much as 50% of the fish meal replaced with soybean meal. Issues relating to the processing of to low value fish and value added product development were determined. Policies and strategies were recommended for market and trade, which helped maintain high quality, safe, and nutritious low value fish products for local and international trade.

While in Vietnam I worked under the direct mentorship of Le Xuan Sinh, PhD., a faculty member of the Fishery Economics and Management Department of the College of Fisheries and Aquaculture of Can Tho University on two projects that are still in progress. These projects are a value chain analysis of the snakehead and a cost benefit analysis of snakehead.

PEOPLE

While working at Can Tho University in the Fishery Economics and Management Department, I worked most closely with Sinh, Mr. Hein, and Ms. Quyen. Sinh, is the Vice Head of the Fisheries Economic and Management Department. We would frequently meet over breakfast to discuss the scope of the projects and what the next steps to be taken should be.

Mr. Hein was the first person I met when I arrived in Vietnam at the airport. I worked with Hein on the cost benefit analysis and he showed me how to use a program called SPSS, a statistical program I had not yet learned. He frequently took me out for lunch during the work week and helped me find my way around. Hein often helped me organize side trips for the weekends as well.

Quyen, a graduate who is now employed by the Fisheries Economic and Management Department and is being mentored by Professor Sinh, first showed me around the campus and the city so I could get settled in. We frequently worked together on projects and I helped her with her scientific writing skills in English and speaking. I am continuing to help her with the food fish consumption project she is currently working on.

Another person I became familiar with in the Department was the Vice Dean of Faculty of the Fishery and Aquaculture Department, Tran Thi Thanh Hein. She told me how she worked extensively with David Bengston, PhD. from the University of Rhode Island to develop a formulated pelleted feed. This pelleted feed relies on soy protein instead of low value trash fish for its protein content. High protein content is required for snakehead feed. However, many people rely on low value trash fish for food, which is most often used as the protein source for snakehead. But, the new formulated feed could reduce the fishing pressure on these low value fish that so many people rely on for a food source.

I also met with Dr. So Nam while in Can Tho, a director and researcher from the Inland Fisheries Research and Development (IFREDI) in Cambodia. He told me how he is conducting research on snakehead in Cambodia. It is currently illegal to grow snakehead in Cambodia because it requires extensive low value trash fish for feed. So Nam hopes that if the project is a success in Vietnam, the new feed technology can be transferred to Cambodia and reopen a fishery, which can offer significant incomes to people.

Figure 1: Myself, Professor Sinh, Ms. Fung, and Ms Quyen.
Figure 2: Fisheries Department and myself barbequing seafood at the university.

RESEARCH IN VIETNAM: VALUE CHAIN ANALYSIS

In order to evaluate the industry we will utilized a value chain, which is defined as "the full range of activities which are required to bring a product or service from conception, through the intermediary phases of production, delivery to final consumers, and final disposal after use" as stated in Kaplinsky and Morris's (2001) Handbook for Value Chain Research. This analysis allowed us to identify barriers of entry along the chain and analyze the interactions between actors in each step of production. Value chains have been used throughout the last two decades, it is a new approach for analyzing global fishery production at a micro-industry level (Pomeroy, 2009). It has already been used by Loc et al (2009) in the MKD of Vietnam and Cambodia to study Pangiasius catfish and Ca Linh. There have been several others.

The objectives of the value chain analysis on snakehead included describing and analyzing the situation of the actors participating in the cultured snakehead industry, analyzing the cost-benefit distribution of the snakehead value chain, and proposing improvements for upgrading this chain so that it is sustainable in the long term. It also identified major actors involved in the chain of cultured snakehead in the Mekong Delta, distinguished the profit distribution of the identified actors, and offered suggestions and ideas for policies that would nurture long-term development of snakehead culture in Vietnam.

My involvement in the value chain analysis project was to review the results from the data collections and help write a publishable paper with Sinh. I was previously given a value chain analysis done on pangasius catfish to better understand how value chains are conducted. Then I was given rough draft of a conference paper outlining the value chain of hard clam and black tiger shrimp to correct and further my familiarity with value chains. This paper was presented to the Tra Vinh's People Committee Council in Tra Vinh. This was a great way to become familiar with this type of analysis before I worked on snakehead.

I then began work on the value chain analysis for snakehead. This value chain analysis identified the five major actors to be farmers, wholesalers, processors, and retailers along with two support groups that included market managers and sector managers. It was also found that the distribution of profit among actors was distributed unequally. Difficulties involved in snakehead culture were observed to be that farmers frequently used live feed, there was a lack of planning in the development of this culture making it difficult to manage, and it was mainly sold domestically. To better aid the development of this culture along with its disadvantages, we recommended that there needs to be better management of capture fisheries, which is consumed by snakehead culture, providing more technical training involving this culture and improving the supply of pelleted feeds. We also thought programs to better facilitate new markets especially export markets would be extremely beneficial.

ECONOMIC ANALYSIS

The aim of producing a cost benefit analysis on the use of the formulated pellet feed was to measure whether the intended effect on the economic development occurred and by how much. Since the overall adoption of the pelleted feed is still an ongoing project this part of the CRSP project is a concurrent assessment, which will evaluate what impediments are occurring that would prevent a larger adoption of the new feed. Some of these constraints can be accounted for by technology traits, policy environment, institutional arrangements, and infrastructure.

Prior to going to Vietnam, I worked with Boris Bravo-Ureta, PhD. on setting up a training lecture that he would give in Vietnam and Cambodia, which taught 12 undergraduates and graduates, 12 scientists and academics, and 10 provincial fisheries officers how to undertake an impact assessment. I helped Professor Bravo-Ureta set up a cost benefit analysis template on Microsoft Excel and a lecture on Microsoft PowerPoint using the data found in The financial feasibility of small-scale grouper aquaculture in the Philippines by Pomeroy et al. (2001) published in Aquaculture Economics & Management. This provided me with the pre-training I needed to help facilitate the impact assessment in Vietnam comparing the costs and benefits of utilizing the new formulated feed versus low value trash fish for culturing snakehead. Unfortunately the data collected from farms that cultured snakehead was provided to me until later than expected during my stay in Vietnam. Therefore, I am currently outlining the best way to organize this data. The data was provided to me on SPSS and I made sure to take the time while in Vietnam to become more familiar with this program as I will be utilizing both SPSS and Microsoft Excel in this analysis. As previously mentioned, Mr. Hein was a life saver because he spent a whole day with me to show me how to use SPSS.

CONFERENCE

Professor Sinh also had me sit in on conference that was led by Flavio Corsin of International Collaborating Center for Aquaculture and Fisheries Sustainability (ICAFIS) where I was introduced to the challenges involved in developing and managing aquaculture, specifically pangasius catfish. A mixture of people with careers as scientists, technicians, and employees of non-profits brainstormed more efficient ways of measuring aquaculture's impact on the environment. One of the ideas I mentioned to Flavio and the group was the lack of analysis or incorporation of already established data on the negative externalities involved in the production of inputs in aquaculture. These may include the production of medicines, transportation of inputs, catching fish in Peru for fishmeal etc.

Figure 3: This is a picture of myself listening to Flavio Corsin lecture us at the workshop on measuring the regional impact of aquaculture.

HANDS-ON LEARNING

I had the chance to visit one of the hatcheries and grow out farm that was interviewed for the value chain analysis only a few hours outside Can Tho. It was called Nhu Y in Phu Tho village, tam Nong district, Dong Thap province. The owners of the hatchery told me they had begun to use the pelleted feed and told me of how they needed to start the fingerlings on trash fish and then wean them off it onto the pelleted feed. They stated that they frequently utilized freshwater trash fish instead of saltwater trash fish because it was usually cheaper and in better condition since it was caught more locally. I found this interesting because one of the key points that Dr. Hein mention in her paper entitled, The replacement of fish meal protein by soybean meal protein with or without phytase supplementation in snakehead (*Channa striata*) diets, which was published in the Journal of Can Tho University, was how salt water trash fish better helped promote growth but I guess the benefit was outweighed by the cost in this specific case.

Figure 4: Nhu Y hatchery/grow-out farm with different hapas that separated different size snakeheads that were being fed pelleted feed.

Figure 5: Quyen, Mr. Hein, and myself speaking with the family who runs the hatchery/grow out farm.

After visiting the hatchery we visited one of the markets and asked the merchants about their snakehead products. They sold whole, fermented, and dried snakehead. The most expensive was the fermented snakehead and the least expensive was the whole snakehead. At this market they sold a variety of live food which included rats, birds, snakes, fish, shrimp, and much more. Professor Sinh translated conversations he had with merchants for me that involved information about the quality, location, and price of different snakehead products being sold.

Figure 6: Boats that transported goods including snakehead to market.
Figure 7: Me behind snakehead being sold.
Figure 8: Dried snakehead.
Figure 9: Fermented snakehead.
Figure 10: Shrimp.
Figure 11 and 12: Birds being sold.
Figure 13: Ducklings for sale.
Figure 14: Rats for sale.)

Since my ultimate goal after finishing graduate school is to involve myself in the aquaculture industry I thought it would be appropriate to become more familiar with the techniques used for culturing fish. This is one of the reasons I chose to go to Vietnam. I was fortunate enough to also obtain hands on training while in Can Tho since the university had its own aquaculture facility that bred, nursed, and grew out fish.

A variety of fish were cultured on campus including snakehead. I observed and participated in the culturing of the carp shown in the pictures below. Once the brood stock was netted from one of the ponds, they were separated by sex. Besides observing the brood sac on females, another way to sex these fish is pretty neat. If you pull on the pectoral fin of a male, their tail will move. After being sexed, the females of were given a dose of LHRA to induce egg deposition. Once eggs were extracted, they were mixed with the extracted sperm from the males. The fertilized eggs were then placed in containers with constantly moving water for sufficient aerated until they developed into fry. They were then transferred to larger tanks and fed zooplankton until they became large enough to digest pelleted feed.

Figures 15, 16, and 17: Vietnamese students capturing the some of the brood stock for culture.

Figure 18: Female carp being sexed. Figure 19: Male carp being sexed.

Figure 20: Students were required to count fish fry, 6000 to a bucket and they told me all of them had to be counted in the one large bucket. I am still not sure if I believe that since there were easily over 100 thousand.

Figure 21: fertilized eggs kept in constantly running water for sufficient aeration.

Figure 22: Fingerling snakehead that were being raised in the hatchery at Can Tho University.

Another aspect of aquaculture I learned about was filtration. In order to carry out such a significant operation on the campus it was essential to have high capacity filters. I had previously built my own filters in the past raising koi on my own but never had the chance to see one of this scale. The water first entered a chamber that moved slowly so as to allow suspended solids to fall out. The water was then pushed into a number of other chambers, each with mediums (usually stone) that were smaller than last. This not only filters the water of solids that may have not dropped out in the settlement chamber but also provides a substrate for beneficial bacteria, which reduces toxic nitrogen levels in the water from fish waste.

Figure 23: This is one of the many filters on the facility.

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Output 4: Impact Assessment on the Use of Low value and small sized fish versus formulated pellet feed for snakehead

Prepared by Le Xuan Sinh, Huynh Van Hien and Justin Grimm-Greenblatt

INTRODUCTION

Increasing demands for fish has resulted in a rapidly growing aquaculture industry in the Mekong Delta region of Cambodia and Vietnam. This increase in aquaculture development has resulted in a complementary increase in the demand for feed, much of which is low value/small sized fish and fish meal, popularly referred to as the "fish meal trap". This has resulted in a growing conflict between the use of low value/small sized fish for aquaculture feed and human consumption. Such an issue has the potential to threaten food security because many people in the Mekong Delta rely on low value/small sized fish for consumption. Furthermore the price of low value/small sized fish has tripled since 2001 and it is predicted to continue to rise as aquaculture expands making it more difficult to afford (FAO-APFIC, 2005).

One fishery that relies heavily on low value/small sized fish and fishmeal for food is the aquaculture of snakehead. Because of the high intensity need for low value/small sized fish, the Cambodian government placed a ban on snakehead aquaculture in 2004. This negatively impacted tens of thousands of snakehead farmers and has led to more illegal fishing activity in the region. However, the snakehead aquaculture fishery in Vietnam has grown substantially and has the potential to increase the conflict between the use of low value/small sized fish used for consumption and feed.

This conflict resulted in a project run by AquaFish Collaborative Research Support Project (CRSP) called, Development of Alternatives to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin of Cambodia and Vietnam: Implications for Livelihoods, Production, and Markets. The objectives of the project are as follows:

1. To domesticate wild snakehead to address the snakehead banning issue in Cambodia in order to lift the ban on snakehead culture in Cambodia
2. To study environment impacts, fish disease and biosecurity of snakehead farming in Vietnam
3. To provide recommendations for policy and best practices development of snakehead farming.

This project focuses on both (1) the aquaculture of carnivorous fish and the management of low value/trash fish by addressing the uses and bio-ecological characteristics of low value/trash fish and (2) exploring alternative feeds and feed technology for freshwater aquaculture. By understanding the social, economic, and environmental/natural resource needs and implications of freshwater aquaculture, this project hopes to create sustainable freshwater aquaculture development in the Lower MKD of Cambodia and Vietnam. This project also takes into account capture and culture fisheries and how they play a significant role in food security, poverty alleviation, and economies within Cambodia and Vietnam. It further addresses the combined management of capture and culture fisheries, and the competition and conflict that has increased between the uses of low value/trash fish for feed and human consumption.

Already, of this project has developed weaning methods so small, hatchery-reared snakehead can quickly adapt to pelleted diets. It was determined that snakehead survive as well on pelleted diets that have as much as 50% of the fish meal replaced with soybean meal. Issues relating to the processing of low value/small sized fish and value added products were determined. Policies and strategies were then recommended for market and trade, which help to maintain high quality, safe, and nutritious low value fish products for local and international trade. These policy recommendations can be found in the Sinh et al (2011) investigation. In order to evaluate the industry Sinh et al. (2011) and to analyze and identify barriers of entry and interactions between actors in each step of production a value chain analysis was used. This is defined as "the full range of activities which are required to bring a product or service from conception, through the intermediary phases of production, delivery to final consumers, and final disposal after use" (Kaplinsky and Morris, 2001).

The project consisted of two phases. Phase I consisted of developing and testing an alternative feed that replaced up to 50% of the fish meal with soy for snakehead culture while Phase II consisted of disseminate information about the alternative feed to farmers and others in the industry that would benefit from this technology. It is to now essential to measure the impact of Phase I (2007 – 2009) and Phase II (2009 – 2011) AquaFish CRSP. This investigation is an impact assessment of the development economics, and extension of pelleted snakehead feed in Vietnam.

MEKONG BASIN AND AQUACULTURE

In the Mekong Delta, which includes Vietnam and Cambodia, aquaculture has the potential to provide lower socioeconomic groups with more food, better nutrition, and increased income. It also stimulates economic growth and offers greater diversification of income (WF, 2008).

For several decades now, aquaculture in the Mekong Delta region of Vietnam has played an important role through its improvements in the provisions of animal protein, creation of jobs, and generation of income for the community. It has also contributed to the domestic consumption and exports of aquatic products of Vietnam. Fish comprise of approximately 70% of the animal protein intake by Vietnamese people in the Mekong Delta. Vietnam ranks third in the world for fish production (Ministry of Fisheries, 2005). Furthermore, Vietnam contributes between 55% and 60% of the total aquatic production of the Mekong Delta (Sinh, 2005). Of that, it produces 60% of the total aquatic production for export by Vietnam (Sinh, 2005). A portion of the fish produced in Vietnam is from aquaculture, which has grown significantly. The annual growth of aquaculture in Vietnam was 10-13% during the last decade.

Cambodia, also located in the Mekong Delta relies on aquaculture which has been growing at a faster rate than Vietnam. Aquaculture increased rapidly over the last two decades, with an average growth rate of 16.3 percent and in 2004 it represented 8.3 percent of total inland fisheries production (So et al. 2005). Rab et al. (2006) stated that it represents approximately 10% of the total inland fisheries for Cambodia and is playing a role towards augmenting fish production in Cambodia (Rab et al., 2006). There is clearly a large demand for fish in Cambodia because fish constitute for approximately 75% of the animal protein intake for the Cambodian households and most of it comes mainly from freshwater fisheries in both fresh and processed form (Hap, 1999).

One important group of species produced in the Mekong Delta is the snakehead; more specifically, the two species currently being cultured in the Mekong Delta are Channa striata, the snakehead murrel, and Channa micropeltes, the giant snakehead. Snakehead production in Vietnam has grown rapidly. In An Giang, Dong Thap, Long An, Can Tho, and Kien Giang Provinces of Vietnam, a total of 5,300 tonnes of snakehead were produced (Long, 2004). By 2008, snakehead production grew to about 30,000 tonnes and in 2010 it reached 40,000 tonnes according to the summary of annual reports of the Delta provinces (Le Xuan Sinh and Pomeroy, 2009; Le Xuan Sinh and Pomeroy, 2011).

The growth of snakehead farming has been quite the opposite in Cambodia due to the Cambodian government placing a country wide ban on the culturing of snakehead, starting in May of 2005. This decision was made because the government believed there were potential negative impacts on both wild populations of snakehead from wasteful seed collection and on lower socioeconomic groups of consumers who suffered from decreased availability of low value/small sized (So Nam and Hang, 2007). So Nam et al. (2009a) revealed that the ban imposed instead had negative impacts such as on the livelihoods of tens of thousands of snakehead farmers who depended on culturing snakehead. Furthermore, it increased pressure on wild snakehead stocks through illegal and destructive fishing gear such as electro shockers (So Nam et al. 2009a).

DISEASE

One issue involved with the production of snakehead in the Mekong Delta is the limitation of appropriate technologies to prevent high fish mortality caused by diseases while culturing. Disease outbreaks among snakehead are caused by 23 genera of parasites, 4 genera of fungi, and 81 strains of bacteria belonging to 5 genera (Pham Minh Duc et al., 2011). Farmers have utilized both modern and traditional medicine to cure disease-infected fish but this has had little success.

LOW VALUE /SMALL SIZED FISH

Another issue with the culture of snakehead is that supplies of small-sized/low value fish are finite, and as indicated by a recent increase in price, i.e. demand is outstripping supply, due to mainly to the depletion of fish stocks resulting from overfishing, human population growth, and ecosystem degradation (So Nam et al., 2009; Le Xuan Sinh and Pomeroy, 2009). Low value small sized fish are typically caught as by-catch, however, some small scale fishers have moved towards directly targeting these species such as a fishing fleet in Cat Lo, Vietnam because of the demand increase for low value/small sized fish (FAO, 2005; FAO-APFIC , 2005).

The lower MKD region is heavily dependent on low value/trash fish for the uses like (1) local consumption (e.g. fresh, dried); (2) direct feed (e.g. livestock, high value species aquaculture); (3) fish meal production (e.g. poultry, aquaculture); and (4) value-added products (e.g. fish sauce). It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products, etc (Un Sophea et al., 2010; So Nam et al., 2009b; So Nam et al., 2009c). Proponents of this suggest small-sized/low value fish be used for food for poor domestic consumers since this would be more appropriate than supplying fish meal plants for an export income, producing high value commodities in aquaculture (Le Xuan Sinh and Pomeroy, 2009). On the other hand, food security can also be increased by improving the income generation abilities of poor people, and it can be argued that the large number of people employed in both fishing and aquaculture has this beneficial effect, via income generation, rather than direct food supply.

While it is difficult to accurately estimate the amount of trash fish caught per year, it appears that the demand for low value/small sized fish will increase as aquaculture in the region increases. In 2008, aquaculture production in Vietnam ranked third in the world with 2,462 thousand tones valued 4,510 million USD (Lymer et al. 2010). The FCR of for snakehead culture is four. Therefore, 120,000 tonnes of low value/small sized fish in 2009 and 160,000 tonnes in 2010 were used for feeding snakehead. This represents 17% and 23% of total annual freshwater fish production in the Mekong Delta of Vietnam in 2009 and 2010, respectively.

FISHMEAL

Low value small sized fish are also bought by fishmeal plants in order to produce fishmeal for pelleted feed for livestock and aquaculture. FAO-APFIC (2005) estimates that 280,000 tonnes of fishmeal is used in fishmeal plants each year. As aquaculture increases in Vietnam, the demand for fishmeal will increase especially for those cultures fed pelleted diets which contain fishmeal. As a result, the fishmeal in pelleted diets will need to be replaced with plant proteins if they cannot compete with fish meal on the local market (FAO, 2005). Piscivorous (fish-eating) fish like cultured snakehead typically require high levels of protein in their diet, reflecting the high protein in their natural diet. The usual source of that protein in pellet diets is fish meal.

Phase I Forumlated Feed Study

To meet the goal of creating pelleted diets, which contain plant proteins, qualitative and quantitative assessments of the regular freshwater low value/small sized fish diet for snakehead food were conducted. Then, a series of formulated feed experiments were conducted in the wet laboratory and in hapas located at the College of Aquaculture and Fisheries (CAF) of Cantho University (CTU) to develop formulated feed for snakehead culture. The experiments conducted were: (i) Weaning methods with formulated feeds for snakehead (Channa striata) larvae; (ii) Replacement of fishmeal with soybean meal (SM) with or without phytase and taurine in diets for Channa striata, and Channa micropeltes; (iii) Utilization of rice bran in snakehead Channa striata feed; (iv) Replacement of fishmeal with soybean meal with additions of soluble fish attractant or alpha-galactosidase in diets for Channa striata; (v) Replacement of freshwater trash fish by formulated feed in snakehead (Channa striata) and (Channa micropeltes) fingerling diets; (vi) Taste analysis of snakehead fed by different feeds.
These experiments concluded:

Thirty-three species of freshwater fish were identified as being used as “trash fish” or low-value fish for snakehead culture and the most abundant and common species is Cirrhinus lobatus. Chemical composition of some common species fluctuated from 14.3 to 16.5, 1.97-8.39, 2.48-4.67 in crude protein, crude lipid and crude ash, respectively. Most of those fishes were commercial species and some of them were target species for aquaculture in Vietnam, such as Anabas testudineus and Trichogaster trichopterus. Therefore, those fish stocks should be assessed and the inland fishery should be managed properly, especially in flood season.

These experiments also conclude valuable information involving the ability to culture snakehead on pelleted feed. Weaning onto formulated feed for snakehead larvae can begin by 17 days after hatch with replacement ratio of 10%.day^{-1} and up to 40% of fish meal in Channa striata and Channa micropeltes fingerling diets can be replaced by soybean meal with phytase supplements with no significant loss of growth performance, feed utilization, or survival of the two species. Rice-bran as well could be utilized by snakehead fingerlings with levels from 10% to 30% without any differences in growth performance and carcass composition. Hence, rice bran could be used in home-made formulated feed for snakehead fingerlings up to 30% to reduce feed cost.

Soybean meal can replace up to 60% of fish meal in the diet with the addition of phytase and alpha-galactosidase or fish solution feeding attractant. However, considering economic efficiency, protein soybean meal only can replace up to 50% of protein fish meal in the diet with the addition of phytase and alpha-galactosidase or fish solution feeding attractant. Moreover, 100% of the fresh water low value/small sized fish can be replaced with formulated feed in the diets of the two species of snakehead. If both growth performance and feed efficiency ratio were of interest, the replacement should stop at 50%. Thus, depending on a farmer’s situation, they should choose their own optimal solution for replacing fresh water trash fish by formulated feed in snakehead culture.

Taste of snakehead raised on a formulated feed was also of concern. C. micropeltes and C. striata fillet quality in a taste test was fairly liked and did not significantly differ between samples. In descriptive pair tests, there was no significant difference between samples. Thus, formulated feed (fish meal or plant protein) did not significantly affect the quality of fish fillet in both C. micropeltes and C. striata compared to a diet of trash fish.

Phase II Technology Transfer

Once the new pelleted feed for snakehead had been developed, it was made available to feed mills in the lower Mekong Delta region of Vietnam. By conducting inception workshops, dissemination workshops, impact assessment seminars, information/communication monitoring, evaluation workshops, and the creation of posters, the public was made aware of the new formulated pellet feed and the issues that surround the uses of low value/small sized fish. Furthermore the dissemination of information facilitated the technology transfer of the new feed technology to training extension workers from seven provinces who then trained farmers.

Methodology of Impact Assessment of Formulated Feed vs. Trash Fish

Agricultural research generates many types of outputs. These include technologies embodied in a physical object (e.g., improved feed), management tools and practices, information, and improved human resources. Impact assessment is a process of measuring whether or not research has produced its intended effect—that of meeting development objectives, such as increases in production and income and improvements in the sustainability of production systems. It is important to demonstrate that the changes observed are due to a specific intervention and cannot be accounted for in any other way. The effects can be measured at the household, target population, national, and regional levels. Impact assessment to be undertaken in this investigation will be of two types: ex-post and concurrent. The ex-post assessment refers to the evaluation made upon the completion of a project to determine achievements and to estimate the impact of research. Returns to investment in research and development are typically assessed using the ex-post concept. These studies also help to understand the process of disseminating technology and the constraints to its adoption. Concurrent assessment or evaluation is done to identify the impediments for larger adoption of the research outputs. The purpose of a concurrent evaluation is to correct the gaps and provide feedback for refining and tuning the technology as per the stakeholders' requirements. Often it is known as constraint analysis. Four components determine the adoption of a technology: technology traits (e.g. duration, quality, etc.), policy environment (e.g. price support, procurement, etc.), institutional arrangements (e.g. seed supply sector, credit availability, etc.), and infrastructure (e.g. markets, roads, power, clean water, processing facilities, etc.). Determining constraints for larger adoption forms a part of the impact assessment.

Eighty three farms that culture snakehead in An Giang and Dong Thap provinces of Vietnam participated in a survey, which obtained information on revenue, fixed costs, and variable costs. This data was entered into SPSS. Of the 83 farms that were surveyed, they were separated by whether they produced two crops per year or another amount of crops per year. Farms that produced two crops per year were the only ones used in this IA. This is because they were the most abundant among respondents and the ratio of capital costs to production may have not aligned with farms producing the same amount of crops per year. Of the farms that produced two crops per year, 37 fed snakehead culture with 100% low value/small sized fish and 44 utilized a pelleted feed. However, of these 44, some were fed a small percentage of low value trash fish and this was incorporated into the variable costs (max 16.10% of total feed on one farm). Farms that utilized 100% low value/small sized fish or pelleted feed were further broken into groups by their crop production. Farms producing 30,000 tonnes/crop of snakehead were chosen as the cut off because this was the median production amount. There were 15 farms producing 30,000 tonnes or less per crop of snakehead and 25 farms producing greater than 30,000 tonnes of snakehead per crop utilizing 100% low value/small sized fish for feed. There were 28 farms producing 30,000 tonnes or less of snakehead per crop and 16 producing greater than 30,000 tonnes of snakehead per crop utilizing pelleted feed. However, one farm produced 400 tonnes of snakehead utilizing pelleted feed and greatly influenced the average. It was therefore treated as an outlier and was not used. This would explain why n=15 for production greater than 30,000 tonnes of snakehead per crop for the pelleted feed group.

Utilizing SPSS, average revenue, average variable cost, and average total cost were calculated and imported into Microsoft Excel to create an enterprise budget. Revenue was found multiplying the average quantity of snakehead produced by the average selling price farmers were receiving.

Fixed costs included miscellaneous and construction of pond costs for farms utilizing 100% low value/small sized fish. It also includes the purchase of machine and construction of pond and culvert costs for both 100% low value/small sized fish and pelleted feed. These were all calculated by dividing the full cost of each item by their respective depreciation rate. This provided the yearly cost of each, which was summed to find the average total fixed cost. It was then divided by two to obtain the cost per crop.

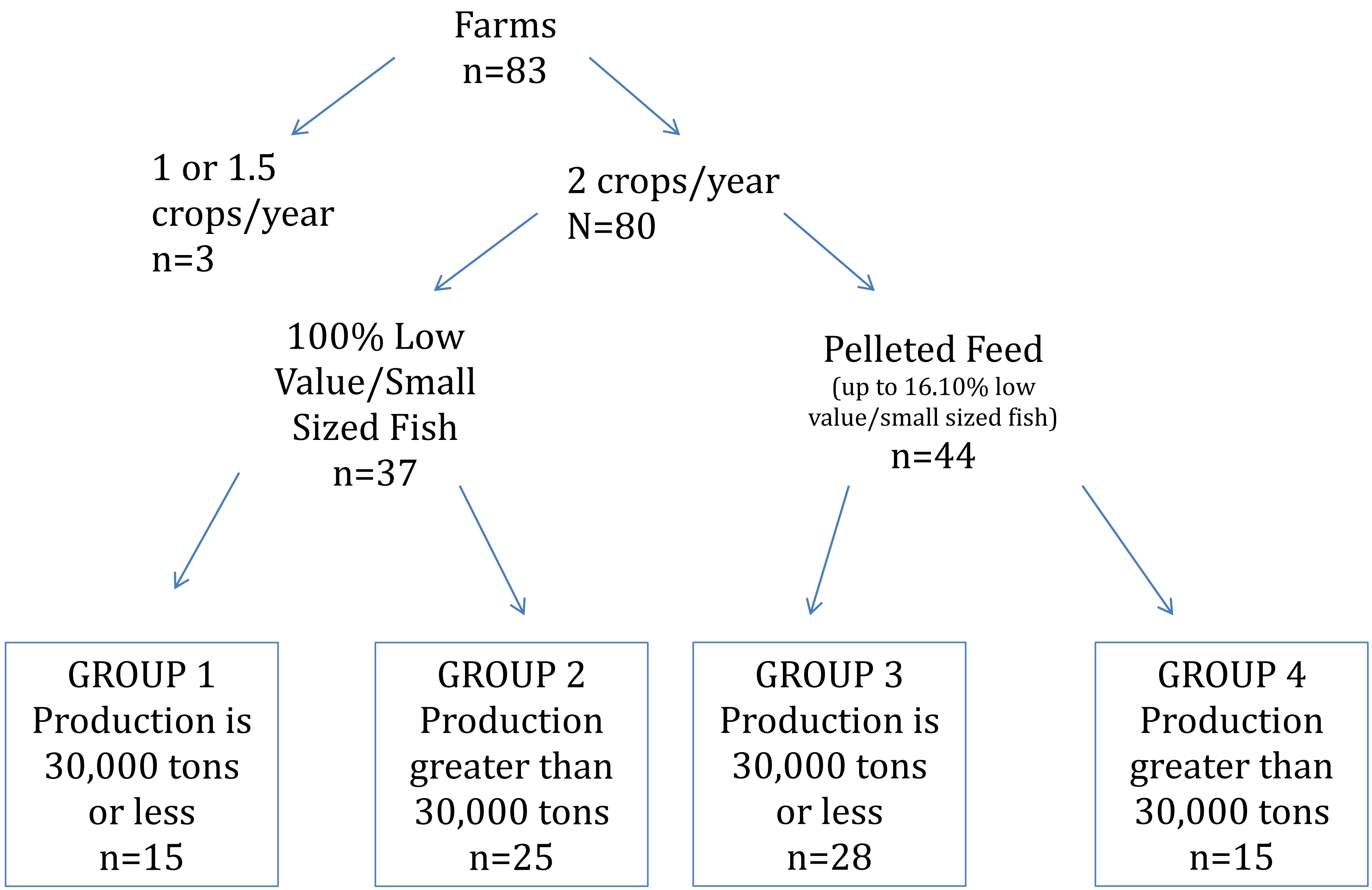

Figure 1: This figure shows how farms were broken into groups before the enterprise budget was calculated. The squared groups are the final groups that were used to calculate averages.

Variable costs included to market costs (transportation to market, boxes, other), tax, seed cost, pump water cost, treatment cost, low value small sized feed cost, pelleted feed cost (for farms utilizing pelleted feed), labor costs (permanent and temporary combined), and interest on loan cost. The data that did not have per unit costs made available by the data included to market costs, taxes, pump water cost, treatment cost, and spawning cost. Therefore, only the full average costs of these items was included. Seed quantity data was also not provided so it was back calculated by dividing the average cost of seed by the average price. Feed (both low value small sized fish and pelleted) were calculated by multiplying the average quantity by the average price. Average interest on loans was calculated by multiplying average interest rate by the loan. This provided the monthly interest rate, which was then multiplied by 6 to achieve the interest cost per crop. Each item was then multiplied by two to obtain the yearly cost.

Average total costs per crop and per year were then calculated by adding average fixed costs and average variable costs. This was then subtracted from the average total revenue per crop and per year to obtain the average net profit per crop and per year.

Next a price sensitivity tests was conducted by altering the price of feed and observing net profit changed within groups 1-4 in figure 1 on a per crop and a per year basis. This sensitivity test was repeated for groups 2 and 4 using equivalent variable costs instead of net profit. For group 3, small farms utilizing pelleted feed, some low value/small sized fish were also part of the cost. However, these were kept constant as pelleted feed prices changed. For group 4, large farms that utilized pelleted feed, some low value/small sized fish were also part of the cost. In this case the price of the low value/small sized fish were adjusted to match the price that group 2, large farms that utilized 100% low value/small sized fish paid.

RESULTS: SMALL FARMS

Table 1. This table shows the revenue, fixed costs, variable costs, and net profit of small farms utilizing low value/small sized fish for feed.

Revenue and Costs of Small Farms Using Pelleted Feed						
Gross Reciepts						
Gross Reciepts	**Quantity per crop**	**Quantity per year**	**Units**	**Price per unit (000'd)**	**Gross Rev. Per Crop (000'd)**	**Gross Rev. Per Year (000'd)**
Total Gross Reciepts	12,453.57	24,907.14	kg	41.92	**522,027.03**	**1,044,054.06**
Fixed Costs						
Fixed Costs	**Total Costs**			**Dep. Rate per yr**	**Cost Per Crop**	**Cost Per Year**
Miscillaneous other cost ('000d)	2,333.33			3.00	388.89	777.78
Construction pond cost ('000d)	29,750.00			3.00	4,958.33	9,916.67
Machine ('000d)	10,562.50			3.92	1,346.20	2,692.40
Construction of damn and culvert ('000d)	41,808.82			9.56	2,186.08	4,372.16
Total Fixed Cost (000'd)					**8,879.51**	**17,759.01**
Variable Costs						
Variable Costs	**Quantity**		**Units**	**Price per unit**	**Cost Per Crop**	**Cost Per Year**
Trans to market (000'd)					4,000.00	8,000.00
Boxes (000'd)					4,416.67	8,833.33
Other (000'd)					3,078.95	6,157.89
Tax (000'd)					6,666.67	13,333.33
Seed cost (000'd)	48,107.14		Ind.	0.26	12,370.41	24,740.82
Pump water (000'd)					6,326.79	12,653.57
Treatment (000'd)					15,160.71	30,321.43
Low value/small sized fish	5,142.99		kg	8.43	43,379.99	86,759.99
Pelleted feed ('000d)	28,500.03		kg	22.02	627,509.64	1,255,019.27
Labor (perm. and temp.) (000'd)					4,388.46	8,776.92
Interest on Loan (000'd)	**Interest rate**	**Loan amount**	**Unit**	**Price Per Unit**		
	1.99	157,720.00	Month	3,140.14	37,511.38	75,022.77
Total Variable Cost (000'd)					**764,809.66**	**1,529,619.33**
Total Cost (000'd)					**773,689.17**	**1,547,378.34**
Net Profit (000'd)					**(251,662.14)**	**(503,324.28)**

Table 2. This table shows the revenue, fixed costs, variable costs, and net profit of small farms utilizing low value/small sized fish for feed.

Revenue and Costs of Small Farms Using 100% Low Value/Small Sized Fish for Feed						
Gross Reciepts						
Gross Reciepts	**Quantity per crop**	**Quantity per year**	**Units**	**Price per unit (000'd)**	**Gross Rev. Per Crop (000'd)**	**Gross Rev. Per Year (000'd)**
Total Gross Reciepts	18,300.00	36,600.00	kg	40.71	**745,071.43**	**1,490,142.86**
Fixed Costs						
Fixed Costs	**Total Costs**			**Dep. Rate per yr**	**Cost Per Crop**	**Cost Per Year**
Miscillaneous other cost ('000d)	4,125.00			7.50	275.00	550.00
Construction pond cost ('000d)	20,898.00			7.67	1,362.91	2,725.83
Machine ('000d)	15,039.92			6.57	1,144.34	2,288.68
Construction of damn and culvert ('000d)	44,000.00			7.67	2,869.57	5,739.13
Total Fixed Cost (000'd)					**5,651.82**	**11,303.64**
Variable Costs						
Variable Costs	**Quantity**		**Units**	**Price per unit**	**Cost Per Crop**	**Cost Per Year**
Trans to market (000'd)					444.44	888.89
Boxes (000'd)					1,687.50	3,375.00
Other (000'd)					1,200.00	2,400.00
Tax (000'd)					2,200.00	4,400.00
Seed cost (000'd)	49,142.86		Ind.	0.31	15,199.18	30,398.37
Pump water (000'd)					66,312.31	132,624.62
Treatment (000'd)					29,807.69	59,615.38
Low value/small sized fish	78,540.37		kg	7.92	622,214.29	1,244,428.57
Pelleted feed ('000d)	0		kg	0	0	0
Labor (perm. and temp.) (000'd)					6,491.67	12,983.33
Interest on Loan (000'd)	**Interest rate**	**Loan Amount**	**Unit**	**Price Per Unit**		
	2.49	312,692.31	('000d)	7,778.22	46,669.33	93,338.65
Total Variable Cost (000'd)					**792,226.41**	**1,584,452.81**
Total Cost (000'd)					**797,878.23**	**1,595,756.46**
Net Profit (000'd)					**(52,806.80)**	**(105,613.60)**

Fixed Cost

Small farms utilizing 100% low value/small sized fish incurred total fixed cost of 5,651.82 (000'd) per crop and 11,303.64 (000'd) per year. These fixed costs consisted of a miscellaneous cost, construction of pond cost, machine cost, and construction of damn and culvert cost, which were 275.00 (000'd) per crop and 550.00 (000'd) per year, 1,362.91 (000'd) per crop and 2,7525.83 (000'd) per crop, 1,144.34 (000'd) per crop 2,288.68 (000'd) per year, and 2,868.57 (000'd) per crop and 5,739.13 (000'd) per year respectively.

Small farms utilizing pelleted feed incurred a higher total fixed cost than the small farms utilizing 100% low value/small sized fish for feed. The small farms utilizing pelleted feed had an total fixed cost of 8,879.51 (000'd) per crop and 17,759.01 (000'd) per year. The small farms utilizing pelleted feed also incurred the same fixed costs, which were miscellaneous costs, construction of pond cost, machine cost, and construction of damn and culvert cost. However, they differ in value from the other farms with costs in the respective order as listed before, 388.89 (000'd) per crop 777.78 (000'd) per year, 4,958.33 (000'd) per crop and 9,916.67 (000'd) per year, 1,346.20 (000'd) per crop and 2,692.40 (000'd) per year, and 2,186.08 (000'd) per crop and 4,372.16 (000'd).
Variable Cost

Small farms utilizing 100% low value/small sized fish for feed incurred a total variable cost of 792,226.41 (000'd) per crop and 1,584,452.81 (000'd) per year. This consisted of to market costs incorporating transportation to market, boxes, and other costs, which were 444.44 (000'd) per crop and 888.89 (000'd) per year, 1,687.50 (000'd) per crop and 3,375.00 (000'd) per year, and 1,200.00 (000'd) per crop and 2,400.00 (000'd) per year respectively. Total variable cost also consists of tax, seed cost, pump water cost, treatment cost, low value small sized feed cost, labor costs (permanent and temporary combined), and interest on loan cost, which were 2,200.00 (000'd) per crop and 4,400.00 (000'd) per year, 15,199.18 (000'd) per crop and 30, 398.17 (000'd) per year, 66,312.31 (000'd) per crop and 132,624.62 (000'd) per year,622,214.29 (000'd) per crop and 1,244,428.57 (000'd) per year, 6,491,67 (000'd) per crop and 12,983.33 (000'd) per year, and 46, 699,33 (000'd) per crop and 93,338.65 (000'd) per year respectively.

Small farms utilizing pelleted feed incurred a lower total variable cost of 764,809.66 (000'd) per crop and 1,529,619.33 (000'd) per year. This also consisted of to market costs incorporating transportation to market, boxes, and other costs. In respective order they were 4,000.00 (000'd) per crop and 8,000.00 (000'd) per year, 4,416.67 (000'd) per crop and 8,833.33 (000'd) per year, and 3,078.95 (000'd) per crop and 6,157.98 (000'd) per year. Total variable cost also consisted of tax, seed cost, pump water cost, treatment cost, low value/small sized feed cost, pelleted feed, labor costs (permanent and temporary combined), and interest on loan cost, which were 6,666.67 (000'd) per crop and 13,333.33 (000'd) per year, 12,370.41 (000'd) per crop and 24, 740.82 (000'd) per year, 6,326.79 (000'd) per crop and 12,653.57 (000'd) per year,15,160.71 (000'd) per crop and 30,321.43 (000'd) per year, 43,379.99 (000'd) per crop and 86,759.99 (000'd) per year, 627, 509,64 (000'd) per crop and 1,255,019.27 (000'd) per year, and 4,388.46 (000'd) per crop and 8,776.92 (000'd) per year respectively.

Revenue, Total Cost, and Net Profit

The revenue achieved by small farms utilizing 100% low value/small sized fish for feed was 745,071.43 (000'd) per crop and 1,490,142.86 (000'd) per year, while the total cost was 797,878.25 (000'd) per crop and 1,595,756.46 (000'd) per year. This caused a net loss of 52,806.80 (000'd) per crop and 105,613.60 (000'd) per year.

Like the small farms utilizing 100% low value/small sized fish for feed, the small farms utilizing pelleted feed were also producing at a net loss. They lost 255,662.14 (000'd) per crop and 503,324.28 (000'd) per year. The revenue for these farms was 522,027.03 (000'd) per crop and 1,044,054.06 (000'd) per year, while the total cost was 773,689.17 (000'd) per crop and 1,547,378.84 (000'd) per year.

RESULTS: LARGE FARMS

Table 3. This table shows the revenue, fixed costs, variable costs, and net profit of small farms utilizing low value/small sized fish for feed.

Revenue and Costs of Large Farms Using 100% Low Value/Small Sized Fish for Feed						
Gross Reciepts						
Gross Reciepts	Quantity per crop	Quantity per year	Units	Price per unit (000'd)	Gross Rev. Per Crop (000'd)	Gross Rev. Per Year (000'd)
Total Gross Reciepts	65,136.36	130,272.73	kg	43.82	2,854,157.02	5,708,314.05
Fixed Costs						
Fixed Costs	Total Costs			Dep. Rate per yr	Cost Per Crop	Cost Per Year
Miscillaneous other cost ('000d)	1,833.33			10.00	91.67	183.33
Construction pond cost ('000d)	48,250.00			9.40	2,566.49	5,132.98
Machine ('000d)	40,538.46			8.40	2,413.00	4,826.01
Construction of damn and culvert ('000d)	77,529.41			9.25	4,190.78	8,381.56
Total Fixed Cost (000'd)					9,261.94	18,523.88
Variable Costs						
Variable Costs	Quantity		Units	Price per unit	Cost Per Crop	Cost Per Year
Trans to market (000'd)					600.00	1,200.00
Boxes (000'd)					10,238.89	20,477.78
Other (000'd)					1,304.55	2,609.09
Tax (000'd)					111.11	222.22
Seed cost (000'd)	180,681.82		Ind.	0.35	63,443.96	126,887.91
Pump water (000'd)					35,500.00	71,000.00
Treatment (000'd)					44,095.24	88,190.48
Low value/small sized fish	231,627.91		kg	8.06	1,866,920.93	3,733,841.86
Pelleted feed ('000d)	0		kg	0	0	0
Labor (perm. and temp.) (000'd)					14,615.26	29,230.53
Interest on Loan (000'd)	Interest rate	Loan amount	Unit	Price Per Unit		
	1.76	742,307.69	('000d)	13,072.43	78,434.57	156,869.15
Total Variable Cost (000'd)					2,115,264.51	4,230,529.02
Total Cost (000'd)					2,124,526.45	4,249,052.89
Net Profit (000'd)					729,630.58	1,459,261.16

Table 4. This table shows the revenue, fixed costs, variable costs, and net profit of large farms utilizing low value/small sized fish for feed.

Revenue and Costs of Large Farms Using Pelleted Feed						
Gross Reciepts						
Gross Reciepts	**Quantity per crop**	**Quantity per year**	**Units**	**Price per unit (000'd)**	**Gross Rev. Per Crop (000'd)**	**Gross Rev. Per Year (000'd)**
Total Gross Reciepts	61,071.43	122,142.86	kg	40.71	2,486,479.59	4,972,959.18
Fixed Costs						
Fixed Costs	**Total Costs**			**Dep. Rate per yr**	**Cost Per Crop**	**Cost Per Year**
Miscillaneous other cost ('000d)	0			0	0	0
Construction pond cost ('000d)	0			0	0	0
Machine ('000d)	4,888.89			1.22	2000.00	4000.00
Construction of damn and culvert ('000d)	70,590.91			10.91	3235.42	6470.83
Total Fixed Cost (000'd)					5,235.42	10,470.83
Variable Costs						
Variable Costs	**Quantity**		**Units**	**Price per unit**	**Cost Per Crop**	**Cost Per Year**
Trans to market (000'd)					0	0
Boxes (000'd)					7,000.00	14,000.00
Other (000'd)					4,480.00	8,960.00
Tax (000'd)					8,000.00	16,000.00
Seed cost (000'd)	219,285.71		Ind.	0.28	60,773.47	121,546.94
Pump water (000'd)					25,642.86	51,285.71
Treatment (000'd)					43,571.43	87,142.86
Low value/small sized fish	6,966.68		kg	8.22	57,266.10	114,532.19
Pelleted feed ('000d)	46,375.84		kg	22.21	1,030,206.22	2,060,412.45
Labor (perm. and temp.) (000'd)					18,900.00	37,800.00
Interest on Loan (000'd)	**Interest rate**	**Loan amount**	**Unit**	**Price Per Unit**		
	0.84	737,500.03	('000d)	6,203.79	37,222.73	74,445.47
Total Variable Cost (000'd)					1,293,062.81	2,586,125.62
Total Cost (000'd)					1,298,298.23	2,596,596.45
Net Profit (000'd)					1,188,181.37	2,376,362.73

Fixed Cost

Large farms utilizing 100% low value/small sized fish for feed incurred a total fixed cost of 9,261.94 (000'd) per crop and 18,523.88 (000'd) per year. This consisted of a miscellaneous cost, construction of pond cost, machine cost, and construction of damn and culvert cost, which were 91.67 (000'd) per crop and 183.33 (000'd) per year, 2,566.49 (000'd) per crop and 5,132.98 (000'd) per crop, 2,143.00 (000'd) per crop 4,826.01 (000'd) per year, and 4,190.78 (000'd) per crop and 8,381.56 (000'd) per year respectively.

Large farms utilizing pelleted feed incurred a lower average total fixed cost of 5,235.42 (000'd) per crop and 10,470.83 (000'd) per year. Unlike large farms utilizing 100% low value/small sized fish for feed, these farms only had fixed costs consisting of a machine cost and a construction of damn and culvert cost. In the respective order they were 2,000 (000'd) per crop 4,000 (000'd) per year, 3,235.42 (000'd) per crop and 6,470.83(000'd).

Variable Cost

Large farms utilizing 100% low value/small sized fish for feed incurred a total variable cost of 2,115,264.51 (000'd) per crop and 4,230,529.02 (000'd) per year. This consisted of to market costs such as transportation to market, boxes, and other costs, which were 600.00 (000'd) per crop and 1,200.00 (000'd) per year, 10,238.89 (000'd) per crop and 20,477.78 (000'd) per year, and 1,304.55 (000'd) per crop and 2,609.09 (000'd) per year respectively. Total variable cost also consisted of tax, seed cost, pump water cost, treatment cost, low value small sized feed cost, labor costs (permanent and temporary combined), and interest on loan cost, which were 111.11 (000'd) per crop and 222.22 (000'd) per year, 66,443.96 (000'd) per crop and 126, 887.91 (000'd) per year, 35,500.00 (000'd) per crop and 71,000.00 (000'd) per year, 44,095.24 (000'd) per crop and 88,190.48 (000'd) per year, 6,344.44 (000'd) per crop and 12,68.89 (000'd) per year, and 78, 434.57 (000'd) per crop and 156,869.15 (000'd) per year respectively.

The large farms utilizing pelleted feed incurred a lower total variable cost of 1,291,948.14 (000'd) per crop and 2,583,896.28 (000'd) per year. Unlike the large farms utilizing 100% low value/small sized fish for feed, these farms had to market costs that consisted of only box cost and other cost. They were 7,000 (000'd) per crop and 14,000.00 (000'd) per year and 4,480.00 (000'd) per crop and 8,960.00 (000'd) respectively. Total variable cost also consisted of tax, seed cost, pump water cost, treatment cost, low value/small sized feed cost, pelleted feed, labor costs (permanent and temporary combined), and interest on loan cost, which were 8,000.00 (000'd) per crop and 16,000.00 (000'd) per year, 60,773.47 (000'd) per crop and 121, 546.94 (000'd) per year, 25,642.86 (000'd) per crop and 51,285.71 (000'd) per year,43,571.43 (000'd) per crop and 87,142.86 (000'd) per year, 5,178,892.86 (000'd) per crop and 10,357,785.71 (000'd) per year, 56,151.43 (000'd) per crop and 112,302.86 (000'd) per year, and 1,030,206.22 (000'd) per crop and 2,060,412,.45 (000'd) per year, 18,900 (000'd) per crop and 37,800 (000'd) per year, and 37,222.73 (000'd) per crop and 74,445.47 (000'd) per year respectively.

Revenue, Total Cost, and Net Profit

The revenue achieved by large farms utilizing 100% low value/small sized fish for feed was 2,854,157.02 (000'd) per crop and 5,708,314.05 (000'd) per year, while the total cost was 2,124,526.45 (000'd) per crop and 4,249,052.89 (000'd) per year. This caused a net gain of 729,630.58 (000'd) per crop and 1,459,261.16 (000'd) per year.

Making a larger portion of profit than the large farms utilizing 100% low value/small sized fish for feed, the large farms utilizing pelleted feed made1,188,181.37 (000'd) per crop and 2,376,362.73 (000'd) per year . The revenue for these farms was 2,486479.59 (000'd) per crop and 4,972,959.18 (000'd) per year, while the total cost was 1,298,298.23 (000'd) per crop and 2,596,596.45 (000'd) per year.

DISCUSSION

Currently there is no time series data available for low value/small size fish prices. However, the Edwards et al. 2004 report for the Australian Centre for International Agricultural Research interviews several farmers and low value/small size fish fishermen from different provinces of the Lower Mekong. It was reported that the price of trash fish rose significantly and in some cases almost doubled from three years prior to the interviews.

This increase in price has already begun to negatively affect farmers, especially small farmers who rely heavily on low value/small size fish, which has resulted in net losses (Table 2). This is shown by the fact that small farms using 100% low value/small size fish for feed were losing -52,806.80 (000'd) per crop and -105,613.60 (000'd) per year. Small farmers utilizing pelleted feed are producing at an even greater loss (-251,662.14 (000'd) per crop and -503,324.28 (000'd) per year) because the pelleted feed is still too expensive. The revenue made by small farmers that utilize 100% low value/small sized fish for feed and ones utilizing pelleted feed are able to cover their fixed costs but not their total costs (table 1 and 2). This is discerning because this is not sustainable in the long run.

In order for these small farms to no longer produce at a net loss, the price of low value/small sized fish or pelleted feed must decrease in price. More specifically, the current price of low value small sized fish for farms utilizing 100% low value/small sized fish for feed must drop from 7.92 (000'd) per kg to approximately 7.25 (000'd) per kg. Since the prices of low value/small size fish has increased significantly over the last decade, this seems unlikely. Therefore, small farms must rely on a decrease in price in pelleted feed. In order for small farms utilizing pelleted feed to be cover their costs the price of pelleted feed would need to drop from its current price of 22.02 (000'd) per kg to approximately 13.18 (000'd) per kg (This is considering that the current price of low value small sized fish for farms utilizing pelleted feed remains at given that the price of low value/small sized fish price remains at 8.43 (000'd) per kg). Furthermore, small farms not exposed to the idea of using pelleted feed would also need to be educated about this option if the price decreased enough.

Large farms on the other hand are incurring a profit and more so for the farms utilizing the pelleted feed (table 3 and 4). It is therefore expected that large farms not using pelleted feed will switch to pelleted feed once they are made aware of its benefits. However, if the price of low small/size fish were to decrease from 8.06 (000'd) to approximately 6.01 (000'd) or less, farmers would begin to switch back to using low value/small sized fish (this is considering that the large farms utilizing pelleted feed pay an equivalent price of 6.01 (000'd) for the small percentage (16.5%) of low value/small sized fish they also use and the price of pelleted feed remains constant). Using equivalent variable costs to find the price at which farmers would begin to switch back to small sized/low value fish, it was found that the price of low value small/sized fish would need to decrease to approximately 4.40 ('000d) per kg or less (this is considering that the price of low value/small sized fish on farms utilizing pelleted feeds is adjusted from 8.22 (000'd) per kg to 8.06 ('000d) per kg in order to match the 100% low value/small sized fish and ones utilizing price paid by farms utilizing 100% low value/small sized fish for feed).

In the case where large farms utilizing pelleted feed begin to switch to low value/small sized fish, the price of pelleted feed would need to increase from 22.21 ('000d) per kg to approximately 32.13 ('000d) per kg or greater (this is considering that the price of low value/small sized fish on farms utilizing pelleted feeds is adjusted from 8.22 (000'd) per kg to 8.06 ('000d) per kg in order to match the 100% low value/small sized fish and ones utilizing price paid by farms utilizing 100% low value/small sized fish for feed) . Using equivalent variable costs to find the price at which farmers would begin to switch to using small sized/low value fish, it was found that the price of pelleted feed would need to increase to approximately 35.91 ('000d) or greater (this is considering that the price of low value/small sized fish on farms utilizing pelleted feeds is adjusted from 8.22 (000'd) per kg to 8.06 ('000d) per kg in order to match the 100% low value/small sized fish and ones utilizing price paid by farms utilizing 100% low value/small sized fish for feed).

CONCLUSION

The future of small snakehead farms is questionable, while large snakehead farms remain profitable. The cost of small sized/fish has increased significantly enough over the last decade to only allow small farms to cover their fixed costs and this is not sustainable in the long term. For the small farms utilizing pelleted feed, the price of pelleted feed is still too high and they also can only cover fixed costs. The future of these small snakehead farms relies on either a decrease in price of low value/small sized fish or decrease in the price of pelleted feed. However, it is unlikely that the price of low value/small sized fish would decrease since it has increased significantly over the last decade. Therefore, it is essential that the price pelleted feed decrease.

In order for the price of pelleted feed to decrease significantly enough to allow small farms to be sustainable, the supply to market must increase. This is likely since large farms relying on pelleted feed are more profitable than large farms relying on 100% low value/small sized fish for feed. Therefore, it is expected that as information about pelleted feed is more widely distributed, more large farms will demand it increasing the market supply and decreasing its prices. However, the rate at which these prices will decrease is unknown and therefore, it is unclear on whether the price will decrease significantly enough and at an appropriate rate to make small farms sustainable in a timely enough fashion.

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Aquaculture & Fisheries CRSP Sponsorship of the Ninth International Symposium on Tilapia in Aquaculture to Be Held in Shanghai, China

Technology Adoption and Policy Development/Activity/09TAP01UA

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ABSTRACT

The ISTA 9 was successfully held in late April 2011 at Shanghai Ocean University. The symposium was held in conjunction with the 9th Asian Fisheries and Aquaculture Forum (AFAF) conference and tradeshow. The Proceedings, co-published by the AquaFish CRSP and Shanghai Ocean University included 62 papers, and 7 posters in a single volume with 409 pages. The entire proceedings were also distributed as PDF files on a USB drive provided to all 1300 participants in the concurrent 9th Asian Fisheries Society Conference. We have since also loaded all of the papers and Power Point Presentations as PDF's on the conference website http://ag.arizona.edu/azaqua/ista/ISTA9/ISTA9.htm. As part of the project we provided travel support for several international scientists to travel to and participate in the symposium.

INTRODUCTION

The Ninth International Symposium on Tilapia in Aquaculture (ISTA9), co-sponsored by the AquaFish CRSP, was held in Shanghai, China, 21-24 April 2011. China has become the world's largest producer, consumer and exporter of tilapia products. The host for the ISTA was Shanghai Ocean University. The scope of the ISTA symposia has closely matched the growth of tilapia farming into a global industry of the second most commonly farmed fish in the world. From the first ISTA with several dozen participants, the ISTA's in Brazil, the Philippines, Mexico, Egypt have each drawn between 600 and 900 attendees. The ISTA 9 was held in conjunction with the 9th AFAF and we had over 1300 attendees in total. Hundreds of thousands of jobs have been created in the farming, processing, and selling of over 3,000,000 MT of tilapia products per year. This enormous quantity of fish has been produced in many of the world's poorest developing nations, providing high quality seafood to their own people as well as the most highly developed markets. This fact was reflected in the diversity of attendees and presentations from attendees representing over 50 different countries.

OBJECTIVES:

1. To provide travel support for Dr. Gonzalez and four international contributors from other Aquaculture & Fisheries CRSP countries to attend ISTA 9.

2. To publish and print the Proceedings of the 9th ISTA. To establish an ISTA website for on-line submission of abstracts and papers and eventual e-archiving of paper and presentations in PDF formats.

TRAVEL SUPPORT

Travel support to the conference was provided for Dr. Pablo Gonzalez and Vicente Camporredondo from Mexico, May Myat NoeLwin, from Thailand, Robert Sayco, from the CLSU-Philippines, Soma Ariyaratne from Sri Lanka, Sidrotun Naim from Indonesia, Pamila Ramotar from Guyana and Loc Tran from Vietnam. By leveraging funds with co-sponsors and encouraging home country partial funding, we were pleased to be able to spread the support so that we were able to bring eight people rather than the five proposed. Two additional persons from Bangladesh were planning to attend, with AquaFish CRSP support, but were involved in serious traffic accident and were unable to travel. Some of their travel expenses could not be recovered.

PROCEEDINGS COMPLETED

The technical sessions included 62 presentations with each presentation having a paper also published in the proceedings. Papers on genetics, nutrition, fish health, processing and food safety, best management practices, marketing and value added products, certification programs, and regional reviews are included in the proceedings. Copies of the ISTA 9 proceedings will soon be available from the World Aquaculture Society on-line bookstore (www.was.org) or from the co-Chairmen, Dr. Liping Liu at Shanghai Ocean University or Kevin Fitzsimmons at the University of Arizona. All of the papers are in English. The proceedings were dedicated to Yang Yi in recognition of his many contributions, not least of which was his desire to host the ISTA9 in conjunction with the 9th Asian Fisheries Society conference at Shanghai Ocean University.

Other past and present CRSP participants making presentations included Remedios Bolivar and four others from CLSU-Philippines, Khalid Salie from Stellenbosch University, Pablo Gonzalez, Wilfrido Contreras and Rafael Martinez from Mexico, Hasanuddin from Indonesia, Dang Thi Oanh, Le Thanh Hung, and Nguyen Phoung from Vietnam and Madhav Shrestha from Nepal. Two University of Arizona students on CRSP support assisted with organizing the abstracts, send papers out for review, collate papers into sessions, and keep records on the internet website. Liping Liu took our PDF files (cover and contents) and found three printers to bid on the printing. The books were delivered to SOU a couple of days before the conference in excellent condition. The ISBN of the proceedings is 978-1-888807-19-6.

CONFERENCE HIGHLIGHTS

The AquaFish CRSP annual meeting was held immediately before the ISTA 9. This allowed many of the CRSP partners to accomplish the annual meeting and the ISTA 9 with only one travel cost. The annual meeting brought the entire AquaFish CRSP group together to review past year accomplishments and learn of future plans and goals for the CRSP and US-AID on a larger scale.

The ISTA 9 itself included simultaneous sessions for two and half days. We also had a section including 9 posters as part of the posters displayed with the Asian Fisheries Society. Lunch and coffee breaks provided opportunities for discussions between delegates to compare results and projects. Many people also took advantage of open periods to visit the downtown Shanghai, the Bund, and other historic and modern sites of the city.

Tilapia dinner. At each of the ISTA's we host a dinner serving locally grown tilapia in traditional recipes. At ISTA 9 we invited 120 people to the dinner (135 showed up, but we were able to accommodate as the hotel had prepared extra food). Tilapia fillets were donated by the Hainan-Quebec Sustainable Company. Several tilapia dishes were served along with the other dishes in a buffet.


Howard Johnson
香煎罗非鱼配香辣奶油汁
Pan-fried Tilapia with Cream Chili Sauce


Howard Johnson
清蒸罗非鱼
Steamed Tilapia with Soya Sauce

REVEREND JAN HEIJNE AWARD

The Tilapia International Foundation presented their award recognizing exceptional career service in support of poverty alleviation through tilapia aquaculture to Dr. LI Sifa from Shanghai Ocean University during the tilapia dinner we hosted at the Howard Johnson Hotel. Named for Reverend Heinje, who organized and supported several tilapia farming projects in developing countries with his congregation in the Netherlands, the award is presented at each of the ISTA events. Dr. LI was recognized for the many years of service to tilapia farming across China, from importing improved strains of fish, to training students, farmers, and government officials, to documenting the growth of the industry across China.

SPONSORS AND SUPPORTERS

Shanghai Ocean University was the host for the symposium. The American Soybean Association provided travel support for one international speaker to attend ISTA9. The China Aquatic Products and Processing Association provided planning support and brought a 10 person delegation to the ISTA. The World Aquaculture Society, American Tilapia Association and Global Aquaculture Alliance (GAA) provided advertising and announcement support. GAA also provided 1000 complimentary copies of their Global Aquaculture Advocate magazine for inclusion in the conference bags. Unfortunately the magazines were held up at customs and were not released until after the conference was completed. They are eventually distributed at another aquaculture conference in a different province. Intervet-Schering-Plough provided $10,000 in unrestricted support which was used to support coffee breaks and lunches. All of these sponsors have requested consideration to continue their support for the future ISTA's. Our current plans tentatively include ISTA 10 to be held at the Jerusalem Ramada Inn in September 2013 and ISTA 11 to be held in conjunction with the Indonesian Aquaculture Society Annual Meeting in Bali in 2015.

Internet-Based Podcasting: Extension Modules for Farming Tilapia in the Philippines

Technology Adoption and Policy Development/Activity/09TAP02NC

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ABSTRACT

The goal of this investigation was to develop a series of podcasts as specialized, internet-based delivery systems for news and technical developments of interest to tilapia farmers. A student at Central Luzon State University (CLSU) and North Carolina State University (NCSU) was trained on podcast technologies. The team subsequently produced a series of six extension podcasts that conveyed feeding practices demonstrated to reduce costs for growout of Nile tilapia. This includes a description of delayed onset of feeding, 67% daily feeding, 50% daily feeding and alternate day feeding at 100% level that serve as effective management measures to reduce feed costs, which constitutes 60-80% of total production costs of tilapia. Collectively, these procedures are shown to improve incomes of farmers with little impact on fish yield. Four of the podcasts were produced in the English language and two others were modified and translated into tagalog, the primary Philippines language. Another two are currently being translated to tagalog. The podcasts contained vocal recordings using monologue and question and answer format, a series of photographs of tilapia farming and cultivation centers, and a music soundtrack. They also contain a number of figures, graphs, and tables that provide experimental protocols, growout data and cost-benefit analyses so users can see the methodology and advantages of different feeding practices in reducing production costs of tilapia growout in ponds. The podcasts were subjected to review, revised accordingly, and uploaded onto the NCSU iTunesU server to track hits, previews and downloads. The podcasts were provided to the CLSU College of Fisheries Computing Center and to the AquaFish CRSP for website upload. Interest in the podcasts has been excellent with 285 downloads and 444 hits on the NCSU iTunes server over a 2-month period, indicating they are an effective tool for disseminating tilapia culture technologies worldwide. The podcasts were also played to 120 participants from the tilapia farming, aquafeeds, government, and academic communities through two workshops on tilapia feeding strategies and feed manufacturing held in two regions of Central Luzon, Philippines. Participants were highly receptive to this mode of disseminating information and were very pleased to see that some of the podcasts were translated into the local language. Collectively, we demonstrate that podcasting is a viable extension tool for disseminating information to the aquaculture community. The podcast approach is far thriftier, more easily updated, and more efficient than the distribution of printed media. With the continued growth of smart phones, MP3 players, computers and other devices in the Philippines and the world we anticipate the Podcast will be a highly attractive tool for dissemination of information on farming tilapia and other cultivars.

INTRODUCTION

Podcasting is an internet-based communication method that is increasing in popularity. In Phase I of our AquaFish CRSP, we produced and uploaded the first Tilapia Podcast to a trackable server at NCSU. It received > 250 hits and was downloaded 76 times in a six-month period alone. The reaction to the initial launch of this current and cutting-edge technology at CLSU during a workshop was equally enthusiastic. CLSU recognizes this medium as an effective and low-cost means of sharing news and technical information. They correctly see it as a technologically advanced process in which CLSU is an innovator and a world leader, as opposed to a follower. The use of podcasts is not restricted to owners or users of iPods, and neither an iPod nor any other MP3 player is actually necessary for participants in and beneficiaries of podcasting. Podcasts can be accessed from desktop computers with internet access, and they are extraordinarily portable – they can be distributed on many cell phones or loaded onto "flash drives" or USB "memory sticks" and passed around among friends, including students and farmers. With a podcast, newly updated sound and/or images can be distributed at practically no cost to end users worldwide, and practical applications of this technology as a means of communication are clearly accelerating. At present there is almost no use of podcasting by aquaculture farmers, although the tremendous potential is clearly being recognized, particularly with the younger generation.

Our CRSP group has generated a range of practical improvements in culture methods of tilapia, some of which have increased the potential profitability for farmers. New feeding paradigms have already been widely recognized as having practical utility for Luzon area fish farmers. The essence of one such series of contributions is the reduction of production costs by using moderate feeding strategies, without incurring any significant loss of product value or quantity (Brown et al. 2000, Bolivar et al. 2003, Bolivar et al. 2006; Bolivar et al. 2010). We have additionally found that fishmeal free and lower protein diets provide cost savings for tilapia farmers (Ayoola 2010; Borski et al. 2011).

The NCSU/CLSU group interacts actively with the fish-farming community. Central Luzon State is an agricultural university and the surrounding fish culture areas are populated largely by families that have relatives and friends who have trained or are training at CLSU. The resulting relationship is an unusually healthy and trusting one – farmers welcome academic input and enjoy both extension and social components of campus life. Past activities of our project have included the production of scientific publications and fact sheets in the form of extension pamphlets, and we have also hosted training sessions and workshops at the School of Fisheries' Freshwater Aquaculture Center at CLSU. Farmers have been involved from the outset in large-scale experimentation and experimental production trials (*e.g.* Bolivar et al. 2006; Bolivar et al. 2010), and the first-hand involvement of farmers in research has a strongly favorable impact on the extension process. Farmers that have volunteered pond space to participate in tilapia production trials are the first to learn of technical advances, and methods that reduce costs and increase profit margins are adopted without additional extension effort. The tilapia farmers in Luzon, Philippines are an ideal group for the advancement of new extension methods. The aquaculture community in this region – the farmers, families, and CLSU fisheries people – are collectively friendly and receptive to innovative academic activities that have a focus on aquaculture.

Among recent extension efforts, our internet-based computing center at the School of Fisheries has grown increasingly popular. This center at the Freshwater Aquaculture Center is readily accessible and is heavily used by commercial farmers. Our Tilapia Podcasting Workshop was held there in early 2009 for the launch of the first podcast on tilapia aquaculture (AquaFish CRSP investigation 07TAP02NC), and was attended by 77 stakeholders, many of whom were already regular visitors to the facility. For this reason, the computing center will continue to serve as an access site for tilapia podcasts, and we propose to involve CLSU students and staff in production aspects of podcasts. We expect increases in both the rate and quality of new podcasts, especially so as CLSU graduate students and fisheries faculty become more involved in the technical components of their production. We also expect the networking and sharing of podcasts to grow – as available information begins to build, students and farmers will be able to download podcasts to digital phones and flash cards, to pass them around among interested user groups. Our goal is to develop a library of practical information in ~5-minute components that can be distributed and shared almost effortlessly and at practically no cost in order to keep farmers technologically current.

OBJECTIVES

1. To build on our initial podcasting efforts by providing a complete series of podcast presentations to interested viewers (farmers, aquaculture students, etc.) to cover basic methods and current topics in a short, attractive, and readily accessible format.
2. Produce a series of short tilapia-related podcasts, as the initial installment in a catalog of introductory and more advanced information on tilapia culture methodology and new production technology that incorporate cost-saving feeding practices. These will be laid out on iTunesU via NCSU, as well as at CLSU College of Fisheries Computing Center and AquaFish CRSP website.
3. Train a student at CLSU and NCSU in podcast technology, to participate fully in the technical aspects of production of Tilapia Podcasts, and to build capacity for future podcasting in the host country. The individuals will train both in-person with project personnel and through online activities.
4. Build a database consisting of digitized materials found to be essential for podcasting purposes to include non-copyrighted photographs and background music – preferably representing the work of students, faculty, and farmers associated with the tilapia production community on Luzon Island in the Philippines.
5. As the layout and content of the podcast websites are developed and refined, efforts will be made to publicize and to promote access to it among aquatic farmers worldwide.

RESULTS AND DISCUSSION

This investigation began with a learning process to use standard but unfamiliar software and hardware that are favored for the production of podcasts. To begin producing a podcast a few essential components are needed to include a computer, microphone and software program for audio recording. Additional features that are often used in podcasts are music, images and video. Garage Band, a program that is commonly used on Apple computers, was selected for our podcast production effort. Adding images, music and several other tracks are possible through this software. Although Garage Band is not compatible with PCs, other programs are. The Window's Sound Recorder is the most basic software used for PC podcasting. Audacity is a more advanced and popular podcasting software and is also compatible for the Mac and Linux operating systems (Broida, 2005). A North Carolina State University (NCSU) undergraduate, Katrina Jiamachello (a Caldwell Scholar) and a CLSU MS graduate student (Roberto Sayco) were trained in podcasting at NCSU over a twelve-week period in 2010. Ms. Jiamachello and Dr. Borski produced a simple user-friendly guide on how to produce a podcast using Garage Band.

The team subsequently produced 6 extension podcasts that conveyed feeding practices demonstrated to reduce costs for growout of Nile tilapia. This includes a description of delayed onset of feeding, 67% daily feeding, 50% daily feeding and alternate day feeding at 100% level that serve as effective management measures to reduce feed costs, which constitutes 60-80% of total production costs of tilapia. Collectively, these procedures are shown to improve incomes of farmers with little impact on fish yield. Four of the podcasts are produced in the English language and two others were modified and translated into Tagalog, the primary Philippines language. The podcasts include the following subjects:

1. Alternate-day feeding strategy for reducing costs of Nile tilapia growout in the Philippines (English)

2. Pag-aaral sa pagpapakain na may isang araw na pagitan upang mapababa ang gastos sa pagpapalaki ng tilapia sa Pilipinas (Tagalog) (English translation: Alternate-day feeding strategy for reducing costs of Nile tilapia growout in the Philippines)
3. A 67% subsatiation feeding strategy for reducing costs of Nile tilapia Growout in the Philippines (English)
4. Evaluation of 50% daily feed ration levels versus full daily feed ration on on-farm growout of Nile tilapia in earthen ponds (English)
5. Pag-aaral sa araw-araw na pagpapakain gamit ang kalahati at buong rasyon ng pakain sa tilapia (Tagalog). (English translation: Evaluation of 50% daily feed ration levels versus full daily feed ration on on-farm growout of Nile tilapia in earthen ponds)
6. Delayed onset of supplemental feeding reduces the cost for growout of Nile tilapia in ponds.

Scripts were all pre-written prior to recordings. The investigators for podcast production built a database of photographs, figures, tables, and original music for producing the podcasts. The podcasts were configured with photographic images depicting tilapia culture in the Philippines, in order to maintain a high level of familiarity and comfort for the farmers in that area. We also provided figures, tables and graphs of experimental outlines, growout data and cost-benefit analyses so podcast users could see the methodology and advantages of different feeding practices in reducing production costs of tilapia culture in earthen ponds. A logo of the tilapia podcast was created (see below). Original music soundtracks recorded by Dr. Gary Wikfors of the NOAA Biotechnology Branch (Milford, Connecticut), were also incorporated into the podcasts. We also took several approaches in producing the podcasts. The scripts for the podcasts took on two major forms that include a standard monologue and a question and answer format. The question and answer format is attractive because it is likely to keep the audience more tuned in as it breaks up the solidity of one voice seen with monologue-oriented production.

The podcasts have been sent out for review and were uploaded at the NCSU iTunesU site where downloads, and other data for podcasts could be collected (http://itunes.apple.com/us/itunes-u/tilapia-podcasts/id380416353). The format for iTunesU changed in the middle of our project so we had to adjust the site such that each of the podcasts is under a general "Tilapia Podcast" theme. Use of the podcast on the NCSU server has been excellent; figures supplied by system administrators indicate that the podcasts received 444 hits and were downloaded 285 times over just a two-month period following their initial upload onto iTunesU (Table 1). Dr. Borski has also received several inquiries about the podcasts from individuals around the world. The podcasts were also provided to the CLSU College of Fisheries Freshwater Aquaculture Center computing facilities and uploaded to the AquaFish CRSP website.

Table 1. Quantification of Tilapia Podcast access from the North Carolina State University iTunesU server over a two-month period after all podcasts were uploaded. Rows indicate the number of "hits" in each month from left to right, while columns indicate the type of "hits" over the seven month period including browses, download previews and downloaded tracks. There were 444 total hits and 285 downloaded tracks over the two-month period from August 2011 – September 2011.

Podcast	**Period**	**Browses**	**Previews**	**Downloaded Tracks**	**Total Hits**
NCSU iTunes U	Aug-11	52			52
	Sep-11	24			24
50% Satiation - English	Aug-11		4	15	19
	Sep-11		3	23	26
50% Satiation - Tagolog	Aug-11		5	38	43
	Sep-11		3	18	21
Altermate Day - English	Aug-11		8	16	24
	Sep-11		10	17	27
Alternate Day - Tagolog	Aug-11		5	16	21
	Sep-11		4	16	20
Delayed Feeding	Aug-11		7	23	30
	Sep-11		5	13	18
67% Satiation	Aug-11		5	23	28
	Sep-11		4	22	26
Book Reviews	Aug-11		10	27	37
	Sep-11		10	18	28
	Total	76	83	285	444

The series of podcasts as extension tools were further disseminated at two January 2011 workshops sponsored by AquaFish CRSP (09SFT04NC and 09SFT06NC): 1) "Tilapia Feeding Strategies and Feed Manufacturing" held at Bacolor, Pampanga and attended by 47 individuals, and 2) "Tilapia Feeding Strategies and Feed Manufacturing: Meeting Global Challenges" held at CLSU, Science City of Munoz and attended by 66 participants representing farmers, and aquafeed company, government, and academic personnel. All were highly receptive to this mode of disseminating information and were very pleased to see that some of the podcasts were translated into the local language.

CONCLUSION

This investigation further demonstrated the practical utility of podcasting as a means of disseminating detailed technical information on aquaculture to appropriate user groups in Luzon Island and the world.

A series of podcasts were produced using different formats to demonstrate the utility of delayed feeding and various feed reduction strategies in enhancing production efficiency of tilapia culture in ponds that can improve incomes for farmers. The podcasts were configured with music and a library of photographic images depicting tilapia culture in the Philippines. They also incorporated a number of figures, graphs, tables that provided experimental outlines, growout data and cost-benefit analyses so users could see the methodology and advantages of different feeding practices in reducing production costs of pond tilapia culture. The series of podcasts were played to over 100 individuals representing the tilapia farming, academic, government and industry communities. The tilapia podcasts were uploaded onto the NCSU iTunes website, CLSU-FAC computing facility and on the AquaFish website. The large number of downloads and hits on the tilapia NCSU iTunesU site indicate the podcasts are an effective tool for disseminating tilapia culture technologies worldwide.

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Development of Alternatives to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin of Cambodia and Vietnam

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Feed Technology and Policy Development for Fisheries Management

Technology Adoption and Policy Development/Activity/ 09TAP03UC and 07TAP01UC

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ABSTRACT

The fisheries resources in Cambodia and Vietnam is faced with drastic decline due to the rapid increase in population and illegal fishing activities - many captured fisheries resources have been largely overexploited as well as the increasing competition and conflict between the use of low value/trash fish for feeding and human consumption. The project entitled "Development of Alternative to the Use of Freshwater Low-Value Fish for Aquaculture in the Lower Mekong Basin, Cambodia and Vietnam: Implications for Livelihoods, Production and Markets" will focus on the balancing of social, economic and environmental/natural resources needed between human consumption and aquaculture feeds based on the development of feed and feeding strategies for other fish species. The cost-effective and high-performing compounded AquaFish Snakehead Formulated Feed (ASFF) was developed to have less reliance on using small-size fish and which would have lower environmental impacts. Up to 40% of small-size fish/trash fish were replaced by new AquaFish Snakehead Formulated Feed, other plant ingredients replaced for fishmeal and enzyme or attract supplementation in diet for optimum growth and survival of the snakehead. However, this new CRSP formulated feed technology was less adopted by snakehead farmers in Cambodia than in Vietnam due to some extent.

INTRODUCTION

Mekong River is one of the most productive aquatic resources in the world. Mekong River is the main source of fisheries resources in Cambodia and Vietnam. Particularly in Cambodia the seasonal and permanent wetlands cover more than 30% of Cambodia. The fisheries sector has for many years contributed significantly to the employment and livelihoods of the poor, to food security, and to GDP and foreign exchange balance. Cambodia's fisheries provide full-time, part-time and seasonal employment for up to 6 million people and the fisheries sector contributes very significantly to domestic food security, providing over 81.5% of the animal protein in the national diet and also forming a critical source of essential vitamins and micro-nutrients.

In addition, the capture fisheries production in Cambodia is estimated to be worth around US$200-300 million per year at the point of landing and fisheries harvesting, processing and trade contributes 8-12%

of GDP. The value of fish exports has been estimated to be as high as US$100 million per year (SPFF 2010-2019).

Fish are also part of Cambodia's cultural heritage. The complex and enduring linkage between fisheries and many aspects of the region's history, as shown by the archaeological finds of fish processing and trade through the region and the incorporation of fish scenes into the historic temples of the country, demonstrates the continuity of the importance of the sector both domestically and throughout the South East Asia region. The aquatic environment and the associated rich diversity of species also constitute a very important part of both the national and global natural heritage.

However, the fisheries resources in Cambodia and Vietnam is faced with the drastic decline of fisheries resources due to the rapid increase of population and illegal fishing activities, many capture fisheries resources have been largely overexploited and, as a result, development of aquaculture has been encouraged to provide the protein, income, employment and export earnings to substitute the natural fisheries resources. In Cambodia, for example, freshwater aquaculture production has increased rapidly over the last two decades, with an average growth rate of 16.3%. In 2004, aquaculture represented 8.3% of total inland fisheries production (So, et al. 2005). In Vietnam, the annual growth of aquaculture has been about 10-13% during the last decade. The Mekong Delta region of Vietnam often contributes about 55-60% of the total aquatic production and more than 60% of total aquatic production for export of the whole country (Sinh 2005). Such a development trend implies that sufficient feed for aquaculture production will be available. One source of feed is low value/trash fish[1] There is a general lack of accurate information on how much low value/trash fish is presently used in Cambodia and Vietnam, but a conservative estimate of 25% for livestock and aquaculture feed has been put forward (FAO-APFIC 2005). The uses of low value/trash fish are diverse and include: (1) local consumption (e.g. fresh, dried); (2) direct feed (e.g. livestock, high value species aquaculture); (3) fish meal production (e.g. poultry, aquaculture); and (4) value-added products (e.g. fish sauce).

There is increasing demand and trade in the region for low value/trash fish for both aquaculture and animal feeds. In Cambodia, for example, it has been estimated that at least 62 freshwater low valued or small-sized fish species are used to feed inland aquaculture. These fish species represent both adult species that are commonly used as food fish, and also juveniles of commercially important fish species. Cage culture uses as much as 50% low value/trash fish in the total feed (So, et al. 2005). In Vietnam, at least 11 species of freshwater, and increasingly a number of marine, low value/trash fish are used to feed inland aquaculture. The price of low value/trash fish has tripled since 2001 and it is predicted to continue to rise as aquaculture expands (FAO-APFIC 2005). The use of artificial fish-based feeds and/or fresh fish resources have further increased pressure on wild fish stocks. Inevitably, a dangerous spiral has evolved where the demand for low value/trash fish for aquaculture feed has supported increased fishing pressure on already degraded resources. It is predicted that as aquaculture grows, it will be difficult to meet the demand for low value/trash fish. There is a general concern that the rapid expansion of aquaculture may ultimately be constrained by the dependence on low value/trash fish and fish meal, popularly referred to as the "fish meal trap". The Asia-Pacific countries may need to increase imports of fish meal from the global market for the aquaculture industry, or replace these with other feed materials. There is a need to address the increasing demand for low value/trash fish by aquaculture by improving feeds for aquaculture through changing over from direct feeding to pellet feeding and reduction of fish meal content by substitution of suitable ingredients in pellets.

[1] Low value/trash is defined as fish that have a low commercial value by virtue of their low quality, small size or low consumer preference. They are either used for human consumption (often processed or preserved) or used to feed livestock/fish, either directly or through reduction to fish meal/oil (FAO-APFIC 2005).

There is also increasing conflict between the use of low value/trash fish for feed and for human consumption. In some cases, such feeds are comprised of fish species traditionally used as cheap food for people and this allocation of fish resources to aquaculture may result in negative impacts of food security and livelihoods. It is the economics of the different uses of low value/trash fish in different localities that direct the fish one way or the other. There are also trade-offs between direct food benefit and the indirect employment and income generation opportunities afforded by feeding to aquaculture. It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products. Proponents of this suggest that using low value/trash fish as food for domestic consumers is more appropriate than supplying fish meal plants for an export, income-oriented aquaculture industry, producing high-value commodities. On the other hand, food security can also be increased by improving the income generation abilities of poor people, and it can be argued that the large volume of people employed in both fishing and aquaculture has a beneficial effect. This raises some important questions regarding the social, economic and ecological costs and benefits of aquaculture, its sustainability and future trends.

In relation to the above-mentioned challenging issues, the project entitled " Development of Alternative to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin Cambodia and Vietnam: Implications for Livelihoods, Production and Markets" was implemented The focus of this project is equally on the aquaculture of carnivorous fish and the management of lower value/trash fish.

The objectives of this investigation aimed to (1) apply the research results and disseminate appropriate technology to the end-users of aquatic resources and aquaculture practitioners, (2) train farmers in the project sites on farm made feeds and benefits of using alternative feed technology, (3) improve feeding practices and promote adoption and change behavior over alternative feeds, and (4) provide scientific-based strategy and information for policy makers to develop policy on aquaculture and aquatic resource management.

METHODOLOGY

This is an activity type of investigation to disseminate information and technology to the end users in form of workshops, conference organization, outreach documents and training sessions. However, the information and technologies can be sent effectively to the farmers, unless we understand on what's the problems encountered by farmers, what's information/technologies farmers needed to overcome the problems, and what is the best way to educate them to solve the problem. Therefore, The Participatory Rural Communication Appraisal (PRCA) was conducted to understand the general characteristic of the farmers in the project sites to develop effective communication channel. Seven provinces, namely Prey Veng, Kandal, Kampong Cham, Kompong Chhnang, Pursat, Battembang, and Siem Reap province were selected for the targeted project sites to transfer the AquaFish Snakehead Formulated Feed.

Two types of data were gathered, primary and secondary data. Primary data was collected through interpersonal interview by using the structured questionnaires which designed to understand the general characteristic of the respondents and the most effective communication channel. Secondary data was collected by reviewing related literatures relevant to fish process technologies and existing practical aquaculture technologies which have been successfully implemented by AIT Aquaculture Outreach Program and JICA Aquaculture Development Program in Cambodia. The review aimed to use the technological know-how and knowledge on local fermented feed made for small scale aquaculture development practiced in Cambodia to transform into the printed media for dissemination.

Orientation within the investigation team members was conducted to internalize the team members to be aware of the project document and understand the requirements needed to be accomplished by the members in the process of project implementation.

Inception workshop was conducted at IFReDI to provide awareness to the government fisheries officers, NGOs representatives, local communities, and other relevant stakeholders on AquaFish CRSP Project implementation, especially, to the other relevant stakeholders whose work related to aquaculture development sector as well as to hold consultation among the participants for their suggestions and recommendations.

Consultation meeting with different team members from three investigations in IFReDI was conducted to provide opportunity to all members implementing the AquaFish CRSP projects in IFReDI to be aware of the process and procedure and also the goals and objectives of the whole project. The consultation established a link of each investigation in terms of its activities, planning, and implementation.

Orientation meeting of all US PIs and HC PIs was conducted in Phnom Penh City. The orientation brought all the US PIs and HC PIs to fully understand the process and procedure of the project implementation. Several issues were discussed during the orientation such as: the activities plan, procedure, time frame, budgetary, and reporting system of each investigation, and set out the mechanism for improving communication within the project teams. It was recommended to use Yahoo Messenger or Skype as communication channel among the team members.

Consultation meeting with local fisheries authority was conducted at commune council, in the Lvea Eam District, Kandal Province to explain the main objective of the investigation and overall project implementation arrangement.

Focused group discussion was conducted to generate information among the snakehead fish culture to obtain first hand information on the nature of snake fish culture and problems that farmers encountered during the culture period such as fingerlings, feed, feeding strategy, as well as disease occurrences.

Consultation meeting with commune council leader, village leader, local fisheries officers and fish farmers was conducted to create criteria for selecting farmers for adoption pilot. Thirty (30) poor and active farmers were selected for CRSP home made feed adoption pilot.

RESULT

The main objective of the investigation is to transfer information, technologies and know-how from research results of the project to the fish farmer and end-users of aquatic resources users in both Cambodia and Vietnam. The Investigation was implemented and achieved the following result:

1.1 Institutional Capacity Building:

Conducted two trainings to build the capacity of the team members, (1) Training on “Development of Questionnaires and Design” and (2) Training on “Data Encoding and Analysis”. The team members were trained on the job to design questionnaires and do pre-testing of data collection method as well as encoding collected data into data form of SPSS computer program. These trainings were designed to strengthening and improving the institutional capacity of the Inland Fisheries Research and Development Institute staffs to learn from the data collection to data entries and analysis.

1.2 Awareness Raising and Technology Transfer:

1.2.1 **Awareness Raising:** carried out public awareness activities in the form of Inception Workshop, Impact Assessment Seminar, Information/Communication Monitoring and Evaluation Workshop, and Poster on Freshwater Small-Size Fish Species in Lower Mekong Basin Cambodia-Vietnam.

- **Inception Workshop:** Conducted inception workshop at IFReDI to provide awareness on AquaFish CRSP project activities. More than 40 participants from both national and provincial government fisheries officers, NGOs representatives, local communities, and other relevant stakeholders participated. The workshop aimed to provide awareness and hold consultation among the participants, particularly the stakeholders whose work related to aquaculture development sector as well as to receive their suggestions and recommendations.

- **Impact Assessment Seminar:** organized seminar to provide awareness to fisheries officers, researchers, local authorities, fish farmers, as well as policy makers to understand the impact of using trash fish for snakehead culture and the reduction of utilization of trash fish by substituting with the rice bran and cassava meal 20-40% with the CRSP formulation of home-made feed. The workshop provided awareness-raising on the important role of small-size fish in daily protein intake of local people and the competition between the human being and the aquaculture industry in Vietnam. The workshop also informed on the diversity of freshwater small-size fish species in Lower Mekong Basin Cambodia and Vietnam. This investigation raised awareness on new alternative snakehead formulated feed developed by AquaFish CRSP.

- **Information/communication monitoring and evaluation workshop:** Conducted workshop on Information/communication Monitoring and Evaluation to 41 participants from different stakeholders such as target snakehead fish farmers, local fisheries officers, and researchers to understand the effective use of printed media as channel to transfer information and technology to targeted farmers.

- **Poster:** Published 5,000 copies of 1st series Poster on Freshwater Small Size Fish Species in Lower Mekong River Cambodia-Vietnam (Photo 7. Poster). The message in this poster is to provide awareness to the audiences on Freshwater Small-Size Fish species diversity in the lower Mekong River Cambodia and Vietnam.

1.2.2 Technology Transfer: Two forms of communication channel, Interpersonal and Printed Media (Poster/Leaflet), were used to transfer technology to the fishermen and other aquatic resources users in the targeted project sites.

- Organized training on Farmer Field School (FFS) to the key fish farmers of the seven provinces of targeted project sites. The training provided opportunity for the fish farmers to get hands on to how to make traditional fish feed by the most successful fish culture farmers in Kandal Province. 26 key fish farmers participated in the training, of whom 11 are female.

- Organized Training of Trainer (ToT) to 21 participants, (3 participants from each province), from seven targeted province project sites. The training designed to build the capacity of the trainees to become a Trainer and also the Extension Worker in order to train other farmers who are interested in adoption of alternative feed for their fish culture. These 21 Trainers/Extension Workers will play a very important role in the dissemination and transferring of AquaFish Snakehead Formulated Feed developed by Investigation III to the fish farmers in Project phase 2 after this new Formulated Feed is confirmed and adopted by pilot farmers.
- Organized training on “Fish Feed Technology” and “Snakehead Alternative Feed” to 30 selected fish farmers for technology adoption pilot. The training was designed to educate

the farmers to understand and have the know-how on CRSP home-made feed for snakehead fish and feeding methodology.

- Organized training on "Logbook Fish Measurement" to 30 selected fish farmers' pilot for feeding and grow rate record keeping.

- **Poster:**
  - Published 20,000 copies of 1st and 2nd series Poster on Freshwater Small Size Fish Species in Lower Mekong River Cambodia-Vietnam. The message in this Poster is to provide awareness to the audiences on Freshwater Small-Size Fish species diversity in the lower Mekong River Cambodia and Vietnam.

  - Published 10,000 posters on "How to Make and Use of AquaFish CRSP Home-Made Feed for Snakehead" and distributed to selected fish farmers and snakehead fish farmers in 6 provinces around the great lake and along the Mekong River.

1.2.3 Institutional Research Collaboration: This project "Development of Alternative to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin Cambodia and Vietnam: Implications for Livelihoods, Production and Markets" provided opportunities for international travels to participate in international conferences and workshop which this opportunity has not only built institutional and staffs capacity but also established networking and linkages between and among the research institutes, universities, and development institutions around the world.

DISCUSSION

The main goal of this investigation is for sustainable freshwater aquaculture development and innovative fisheries management systems in the Lower Mekong basin region of Cambodia and Vietnam. This main goal takes into account that the main driver of this project is the continued expansion of aquaculture and its dependency on capture fisheries for low value/trash fish for feed. It also takes into account that: capture and culture fisheries continue to play an important role in the food security, poverty alleviation and economies of both countries; the strong interdependency between capture fisheries and aquaculture; management of these two sub-sectors cannot be carried out in isolation of each other; there is increasing local and intra-regional trade for low value/trash fish products; and there is increasing competition and conflict between the use of low value/trash fish for feed and human consumption.

Balancing of social, economic and environmental/natural resource needed between human consumption and aquaculture feeds are based on the development of feed and feeding strategies for other fish species, further on-farm trials of feed formulations, policy and technology for trade and value-added product development for low value/trash fish, development of farm made feeds, improved management strategies for capture fisheries, and policy development for sustainable aquaculture and capture fisheries.

Investigation 09TAP01UC in the first phase of this project (*Implementation Plan 2007–2009*) had problems due to underestimating that the new technology for snakehead formulated feed will be developed by the first year of the project implementation. But the development of AquaFish Snakehead Formulated Feed took longer time than our expectation. This investigation in the second phase of the project (*Implementation Plan 2009–2011*) is continued to develop the new technology for snakehead formulated feed with cost-effective and high performing compounded feeds that had less reliance on using trash fish and which would have lower environmental impacts. The study designed to determine the capacity of trash fish that could be replaced by new AquaFish Snakehead Formulated Feed, other plant ingredients replaced for fishmeal and enzyme or attract supplementation in diet for optimum growth and survival of snakehead.

The new AquaFish CRSP developed technology for snakehead formulated feed was commercialized by more than 10 snakehead feed producers in Mekong Delta Vietnam with remarkable results, proven and adopted by the farm trials and farmers pilot adoption as well as snakehead farmers in general.

Thirty (30) snakehead farmers were trained on new CRSP AquaFish homemade feed in Lvea Em District, Kandal Province in Cambodia for farmer adoption pilot. The farmers can replace their trash fish by rice bran and cassava up to 30-40%. However, the farmer adoption rate was high during the first month after stocking fish and most of snakehead farmers stop feeding their snakehead with CRSP home made feed after three months due to: (1) their fish getting big after three months and can eat trash fish with grinding, (2) the cost of rice bran and cassava the same as cost of trash fish, and (3) homemade feed pay more cost on gasoline for engine to grind and labor cost to mix the feed.

On the other hand, the new CRSP AquaFish Snakehead Formulated Feed and Homemade Feed were publicized for broader fish farmers, aquaculture practitioners, and commercial uses through printed materials such as poster, leaflet, trainings, extension workers as well as workshop to disseminate this new CRSP AquaFish Snakehead Formulated Feed technology to peer and relevant researchers to achieve the overall objective to transfer the adoption of new feed technology to the end users.

CONCLUSION

The project addressed a critical gap in terms of institutional capability of Inland Fisheries Research and Development Institute (IFReDI) to implement information and communication interventions targeted at specific users of fisheries resources who are causing fisheries resources degradation problems that affect fisheries and aquaculture productivity, profitability, and food security. The project has built not only institutional and staff capacity but also established networking and linkages between and among the research institutes, universities, and development institutions around the world.

The project addressed urgent fisheries resources degradation problems which are related to improper uses of feed technology in aquaculture development and other agricultural activities around the Great Lake, in particularly, and in the Lower Mekong River Basin Cambodia and Vietnam, in general. More than 20,000 of farmers are aware of Freshwater small size fish species diversity through the publication of poster. The project provided awareness on the importance of balancing use of freshwater small size fish in the Lower Mekong River Basin in Cambodia and Vietnam. The project has established effective linkages between researchers and communicators. The research results were applied to develop appropriate technologies to disseminate technical information and provide awareness and better understanding of the importance of low value fish, feed meal technology and feeding practices to the fish farmers which significantly reduce dependence on capture trash fish for feed and feeding in aquaculture activities.

The project produced more impact and benefit to farmers and users of aquatic resources after the new AquaFish Snakehead Formulated Feed and homemade feed has been tested, proven, and adoption by farm trials and farmer adoption pilot. The adoption of new CRSP AquaFish formulated feed and homemade feed led to reduction of the utilization of small size fish for snakehead culture in both Cambodia and Vietnam.

ANTICIPATED BENEFITS

These investigations provided direct and indirect benefit to different stakeholders such as: group of fish feed producers, fish farmers, aquaculture specialists, extension workers, and the people who live in

Mekong Delta. Especially, women, children, and elders whom often involved in fish made feeds and fish feeding practices.

More than 1,000 fisheries officers, NGOs representatives, local authorities, and other stakeholders worked related to aquaculture, fish farmers, and fishermen in the lower Mekong basin of Cambodia and Vietnam were aware and informed on the project implementation. Moreover, 47 of fish farmers in Cambodia were trained on farm made feeds, feeds and feeding strategies and 21 of key fish farmers were trained in a training of trainers to become extension workers. More than 20,000 farmers were aware and gained knowledge on species diversity and composition of freshwater small size fish in Mekong River Basin of Cambodia and Vietnam through the CRSP Poster. More than 10,000 fish farmers and aquatic resource users received relevant information and appropriate technologies on CRSP AquaFish Snakehead Formulated Feed and homemade feed technology. However, the new CRSP AquaFish formulated feed and homemade feed technology will continue to be widely disseminated to other fish farmers, aquaculture practitioners, feed makers, and other aquatic resource users in Cambodia and Vietnam even though the project finished.

ACKNOWLEDGEMENT

The author wishes to express his deep gratitude and heartfelt thanks to the United State Aid for International Development (USAID) and people of America for its financial support to the project implementation as well as to the Aquaculture and Fisheries Collaboration Research Support Program (AquaFish CRSP) Management Entity Director, Dr. Hillary Egna, for her patience, encouragement, untiring support, and guidance until the completion of the first phase of project implementation. Her advice has been a constant source of inspiration and her moral support is deeply appreciated.

Sincere thanks and appreciation are extended to Dr. Robert S. Pomeroy, US Lead PI, Dr. Sylvain De Guise, and Tessa Getchis from University of Connecticut, Dr. David Bengtson, University of Rohde Island for their constant assistance and advice to improve and complete the project implementation.

Deep appreciation and special thanks are wished upon all the AquaFish CRSP Management Entity staff and officers at the Oregon University for sharing their knowledge, experiences, and guidance.

Special thanks to H.E Dr. Chan Sarun, Minister of Agriculture, Forestry and Fisheries for his constant support and advices, H.E Dr. Nao Thuok, Director General of the Fisheries Administration, Mr. Khleang Vanthol, Director of Kandal Provincial Fisheries Cantonment, for their support during the field research in Cambodia and his heartfelt thank are extended to Mr. Nguyen Van Ngo, the Director of Dong Thap Provincial Aquaculture Department in Vietnam for his support to the project team’s field work in data gathering in Vietnam.

Finally, the author would like to delicate this work this work to the respondents, fishermen, fish farmers, Fisheries communities, and local authorities in both countries Cambodia and Vietnam who made time out of their busy schedules for the interview.

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Harnessing the Opportunities and Overcoming the Constraints to Widespread Adoption of Cage Aquaculture in Ghana

Technology Adoption and Policy Development/Study/09TAP04PU

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EXECUTIVE SUMMARY

Sub-Saharan Africa has abundant land and water resources, but these have not been tapped to increase aquaculture production significantly in global terms. Recent analyses of Sub-Saharan Africa aquaculture have noted a relative lack of public sector research and development attention to alternative culture systems (e.g., cage culture) in Africa and recommended increased attention to alternative production systems while striving to increase intensity and production from the traditional earthen ponds. Likewise, the analyses identified progress made in Nigeria and Egypt in the production of species other than the tilapias as dictated by local demands for those alternative species, leading to their recommendations for expansion of production of high-demand indigenous species for niche markets. As a business model, diversification of species and systems provides a safety net and access to new markets for investors. This project involved complementary investigations of the opportunities and challenges to the adoption of cage culture as an alternative production system in Ghana, experimental studies of nutritional requirements and a market survey of indigenous, non-traditional aquaculture species with potential for development.

In the study of constraints and opportunities in cage aquaculture in Ghana, lack of capital to initiate a business and buy inputs especially high quality imported floating feeds was the most important constraint identified followed closely by inadequate extension services. On the other hand, prospects of local feed production were reported and some financial institutions indicated willingness to lend money for aquaculture if properly guaranteed. Government and NGO's microfinance options are also emerging opportunities. To make up for some of the deficiencies in extension services and training, a group of farmers who participated in this study and indicated they needed more training were funded to attend a one day workshop on Low Volume-High Density cage culture systems held at Crystal Lake Fish Farms in Ghana.

This investigation has produced valuable insight not previously available to farmers and the private sector of Ghana, the Fisheries Commission of Ghana and other relevant government institutions. We expect these results to contribute to diversification and rapid acceleration of aquaculture development in Ghana and the sub-region. A comprehensive Strength Weaknesses Opportunities and Threats (SWOT) analysis of the aquaculture industry in Ghana is underway utilizing lessons learned from past, the current, and ongoing AquaFish CRSP projects. This analysis is being undertaken with input from the Fisheries Commission of Ghana.

ABSTRACT

This study was conducted to identify why the overall contribution of the aquaculture industry to local fish production in Ghana is low (<1%) although cage aquaculture has a potential to increase production. We administered 134 questionnaires to six respondent groups (current cage fish farmers, potential adopters of cage aquaculture, farmers who have abandoned cage aquaculture, Fisheries Commission, regional and district fisheries officers, and financial institutions) to obtain insight into the constraints in cage aquaculture as well as opportunities that can be exploited to promote cage aquaculture adoption. For the purpose of this study, potential adopters are individuals who have fish-related livelihoods including fishermen, pond-based fish farmers, and fish traders. We also interviewed key informants in relevant government institutions. Preliminary results indicate that lack of capital and lack of government extension services are the main constraints in cage aquaculture in Ghana. Lack of capital manifests in farmers' inability to afford quality floating feed and could explain low production levels of current cage farmers, although most (95%) suggested they could market their fish if they increased production. Lack of capital also accounted for the inability of potential adopters and farmers who have abandoned cage aquaculture to start or continue cage aquaculture respectively. Major opportunities identified include 1) a high interest among potential adopters (79%) to start cage aquaculture and farmers who have abandoned cage aquaculture (100%) to resume if constraints are removed, 2) development of a feed production plant in Ghana by a private enterprise, 3) willingness of some financial institutions to provide loans for cage farmers, and 4) a number of government initiatives to promote cage aquaculture. Our preliminary recommendations are that the Fisheries Commission should work with the financial institutions to help determine farmers' ability to repay loans and guarantee loans made by the financial institutions. Also, there is a need for a more specialized aquaculture extension service accessible to farmers to help with technical issues built on the model of agricultural extension services in Ghana.

INTRODUCTION

Aquaculture in Ghana has been predominantly land-based since its inception in the 1950's. There are currently about 4,500 ponds operated by more than 2,800 fish farmers in Ashanti, Brong Ahafo, Central and Western Regions of Ghana (Lionel Awity, unpublished data). Despite these numbers the contribution of aquaculture to local fish production is still insignificant. Available data suggests that the output from aquaculture in 2006 was estimated to be less than 1% of local fish production (Abban *et al*. 2006). Increasing aquaculture production will be a major step towards food security in Ghana and a further step in achieving 20% of local production, similar to the global mean, which the government seeks (Abban *et al*. 2006). In order to achieve this goal in addition to meeting the estimated annual deficit of 400, 000 mt (Asmah 2008), cage aquaculture must be given serious consideration since land-based aquaculture in Ghana is mostly extensive and the land is finite.

The country offers considerable opportunity for small-holder and commercial scale development of freshwater cage aquaculture, especially in the Volta Lake. Utilizing only 1% of the area of Volta Lake (approximately 8502 km^2) (ILEC 1999) corresponds to about 8500 hectares of water. This quantity of water is more than 10 times the area used for land-based aquaculture, about 468 hectares, estimated with 1,300 farms with mean size of 0.36 hectares (Asmah 2008). The culture of other desirable species such as the catfishes can also be expanded through cage aquaculture in addition to Nile tilapia (*Oreochromis niloticus*) which is currently the only species cultured in cages in Ghana (Blow and Leonard 2007). There is no doubt that cage aquaculture has the potential to make significant contribution to total fish production and food security in Ghana. China is a good example of a country where cage aquaculture has played an important role in inland fish yields. During1978 to1993, production from cage aquaculture accounted for 67.5% of total fish production of inland water bodies (Baotong and Yeping 1997). Even in Ghana, a single commercial cage farm contributed about 21% (200 tons out of 950 tons) to total aquaculture production in 2004 (Awity 2005). It has been suggested that if cage farmers in Ghana can produce yields of 50-150 $kg/m^3/9$ months as done elsewhere in Africa, less than 100 hectares of fish cages can produce yields matching the current capture fisheries production of 90,000 mt (Ofori *et al*. 2010).

Evidently cage aquaculture is not without negative environmental impacts. However, most impacts can be avoided if appropriate policies are implemented to limit the area of water allocated for cage aquaculture, which is currently being considered (Lionel Awity, pers. comm.). Existing irrigation reservoirs also have the potential to be used for cage aquaculture since they are less likely to raise major concerns.

Obviously, having significant national water resources for cage aquaculture is an important first step, but national development policy for cage aquaculture should be cognizant of other complex and interacting constraints to cage aquaculture development as have already been documented elsewhere (Hambrey 2006). Cage aquaculture has been developing in Ghana consistently in the last decade but there have been no significant reflection in the overall aquaculture production figures. Major constraints to aquaculture development suggested for Sub-Saharan Africa are feed and seed quality and availability, cost of cage design and construction, and financing (Ridler and Hishamunda 2001; Halwart and Moehl 2006; Moehl *et al*. 2006; Blow and Leonard 2007; Asmah 2008). Other constraints identified include lack of technical know-how (Ridler and Hishamunda 2001; Halwart and Moehl 2006; Blow and Leonard 2007; Asmah 2008), lack of market (Hambrey 2006; Moehl *et al*. 2006), lack of processing (Blow and Leonard 2007), lack of access to information and support (Ridler and Hishamunda 2001; Moehl *et al*. 2006; Asmah 2008), conflict over water use (Halwart and Moehl 2006) among others.

Many of the constraint suggested have been attributed to aquaculture in general and are likely to be constraints facing cage farmers but because they are mostly described for the entire sub-Saharan Africa, it becomes difficult to develop policy strategies and solutions targeting specific constraints. It is imperative that each country identifies its specific set of constraints and prioritize development interventions accordingly.

Our goal was to identify why the overall contribution of the aquaculture industry to local fish production in Ghana is low although cage aquaculture has a potential to increase production, and make necessary recommendation to the Fisheries Commission aimed at developing interventions for expanding cage aquaculture. Our specific objective was to identify the main constraints to cage aquaculture in Ghana. We also sought to identify any opportunities that could be exploited to increase the contribution of cage aquaculture to fish production in Ghana.

Description of the study area

The study was conducted in communities around the Volta Lake where there are present or past cage aquaculture activities. Lake Volta is currently the main inland water body used for cage aquaculture in Ghana. It presents enormous opportunities for aquaculture expansion. Communities around the lake are mainly engaged in fishing and farming employing mostly men with the women focusing on fish processing and trading. Lake Volta and its tributaries drain 70% of the entire area of Ghana (FAO 2005) covering mostly Northern, Volta, Eastern and Brong Ahafo regions. The Eastern and Volta regions were the focus of this study. We selected the respondent groups from several districts in these regions based on the recommendations from the Fisheries Commission.

METHODS

Sample selection and data collection

The surveys were done with three main respondents including current cage fish farmers (Adopters), cage fish farmers who have abandoned the trade (Abandoned), and Potential Adopters represented by people with fish-related livelihoods such as pond aquaculture and trading in fish. The other respondents were the Fisheries Commission, regional and district Fisheries Officers, and representatives of financial institutions. The group consisted of people already employed in fish activities including fishermen, pond and pen-based fish farmers and fish traders. Regional and district Fisheries Officers of the Fisheries Commission function as extension officers to fish farmers in addition to their prescribed duties. Therefore we included this respondent group to learn about their perspectives of what the constraints in cage aquaculture in Ghana were.

With the exception of Potential Adopters and financial institutions, all respondents identified for this study had small populations which were easily accessed through census. We obtained a list of Adopters and Abandoned from the Fisheries Officers and contacted as many as were available. Where we could not contact farmers directly, we employed opinion leaders to help access them. We also interviewed financial institutions based on their availability and preparedness to voluntarily answer questions.

The field studies were conducted the summer of 2010 and 2011. We employed both surveys and interviews in this study. We administered most of the questionnaires in person to ensure answers provided were directed to exact questions asked. A total of 134 questionnaires were administered. Questionnaires were structured to suit respondent groups but we incorporated similar questions across some questionnaires to aid comparison among groups. We interviewed 45 Adopters, 20 Abandoned (including 10 individuals who had abandoned pen fish farming), and 57 Potential Adopters. We also administered 1 questionnaire to the Fisheries Commission, 5 questionnaires to regional and district Fisheries Officers, and 6 financial institutions identified in the two regions used in this study. We further interviewed key informants in relevant government institutions.

Questionnaire design

Based on the information available in the literature about constraints in aquaculture in general and cage aquaculture in particular we developed nine items representing constraints that could be evaluated by Adopters, Abandoned and Potential Adopters. The nine items were presented and scored on a four-point interval scale ranging from "not important" to "very important" modified from Vagias (2006) level of problem type-scale. Respondents were to rank the constraints according to how important they were in their cage aquaculture operations, their decision to abandon or adopt the business. Additionally we presented the same set of constraints to the Fisheries Commission and the regional and district Fisheries Officers. We also provided an open-ended option for respondents to state other constraints they thought were very important.

Adopters, Abandoned and Potential Adopters were asked to indicate (yes/no) whether they had had specific cage aquaculture training. We followed up with an open ended question of the type of training, where and when they had the training. We used these multiple measures of training as a way of assessing the level of knowledge of respondents in cage aquaculture.

We also wanted to evaluate the market availability for products, the profitability of cage aquaculture from the respondents' perspective, and interest in the business. To do this we developed a series of binary response questions which were presented to the appropriate respondent groups. We asked Adopters to indicate (yes/no) whether they thought they would be able to sell more fish if they could expand production above their current level. Then we asked them if they would recommend cage aquaculture to potential farmers. To evaluate the level of interest, we asked Potential Adopters to indicate (yes/no) whether they were interested in starting cage aquaculture on the Volta Lake. We further asked both Abandoned and Potential Adopters to indicate (yes/no) if they were interested in resuming or starting cage aquaculture if constraints are removed, and to provide reasons for their responses.

Opportunities available for farmers to access loans from banks and financial institutions were explored through both close-ended and open-ended questions. Financial institutions were asked to indicate (yes/no) if they had given loans to fish farmers in the past. When the response was yes, they were further asked to indicate the percentages of farmers who paid the loan at the appointed time, sometime after the appointed time or never repaid the loan. Future opportunities for loans were explored by asking financial institutions to indicate (yes/no) whether they had some form of budget for fish farmers currently. For those that responded in the affirmative, we asked them to provide specific requirements that farmers needed to meet in order to access a loan.

Interviews

We used select questions from the questionnaires as an interview guide in conducting the interviews with the key informants in government research institutions. We asked interviewees their opinions about the constraints in cage aquaculture in Ghana and opportunities they knew existed which could improve the industry. We took notes in all interviews but taped none of the interviews to avoid making interviewees uncomfortable.

In this preliminary analysis, the quantitative questions in the surveys were analyzed using descriptive statistics such as arithmetic means, percentages and proportions and the qualitative questions were either coded and analyzed using descriptive statistics or analyzed qualitatively. All interviews were transcribed and stored to await analysis with the surveys.

RESULTS AND DISCUSSION

Constraints in cage fish farming

Overall, the three main respondents groups (Adopters, Abandoned and Potential Adopters), the Fisheries Commission, and regional and district fisheries officers ranked lack of capital high on a 4-point scale. Mean ranking of lack of capital was 3.5 for Adopters (Figure 1). Abandoned and Potential Adopters had mean rankings of 3.3 and 3.2 respectively. Due to the small sample size of the Fisheries Commission, and regional and district fisheries officers (n = 1 and 5 respectively), their means were not included in the comparisons but it is worth mentioning that the Fisheries Commission ranked lack of capital as very important (4) whiles the regional and district officers had a mean ranking of 4 for the same constraint.

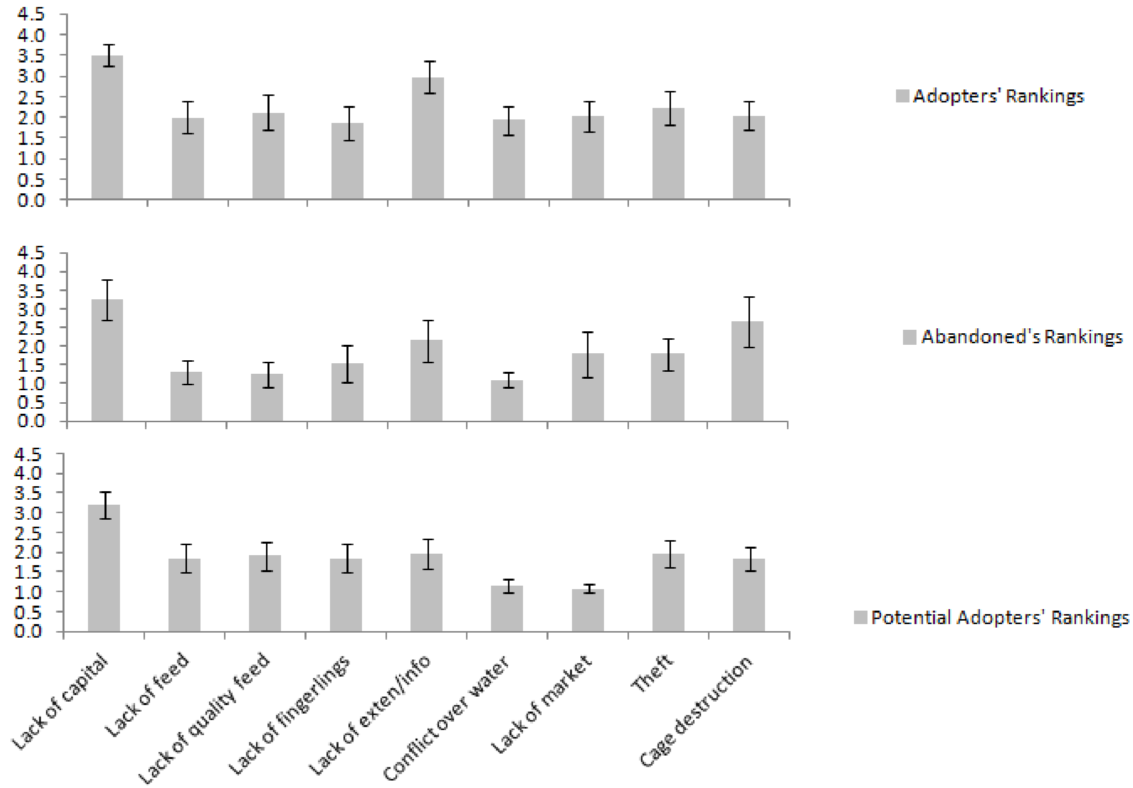

Figure 1.- Mean rankings of nine constraints for Adopters, Abandoned and Potential Adopters. The ranking is based on a 4-point scale from not-important to very-important. Total sample size (n) for Adopters, Abandoned and Potential Adopters are 45, 20 and 57 respectively. Error bars are 95% confidence intervals.

The results from the survey suggest that lack of capital is the main constraint in cage aquaculture in Ghana and not lack of feed and fingerlings as has been suggested for Sub-Saharan Africa (Halwart and Moehl 2006). Rather, the problem appears to be high input cost, specifically, feed cost due to the importance of feed in the relatively intensive system of tilapia cage aquaculture. Lack of good fingerlings may have been a constraint in the past but with the extensive research conducted by the Aquaculture Research and Development Centre of the Water Research Institute (CSIR-WRI) to improve the genetic quality of tilapia broodstock and fingerlings, and the availability of many commercial hatcheries, lack of fingerlings is probably a problem of the past in Ghana. When the respondents were asked to state other constraints they thought were important, high feed cost emerged as the most important constraint. Additionally, extra information provided by some respondents indicated that high feed cost was an important constraint not the lack of feed or lack of good quality feed (Figure 2). It is therefore reasonable to conclude that farmers lack capital to buy feed for their business because quality feed are often imported. This result corroborates the opinion of Blow and Leonard (2007) that the unavailability of high-quality locally produced feeds at competitive prices in sub-Saharan Africa was a constraint in cage aquaculture. High feed cost also translated into high fish price, which some farmers felt affected their profit (Figure 3) even though lack of market was not necessarily a major constraint according to the survey results.

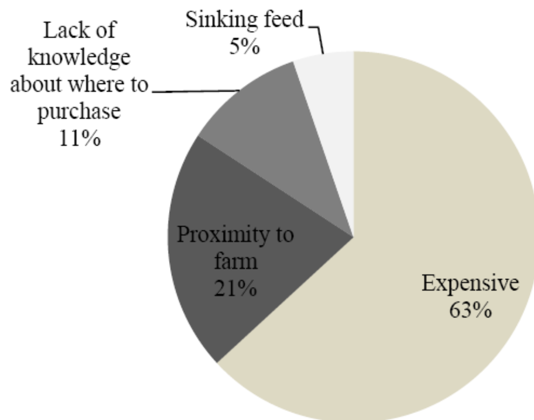

Figure 2.- Proportion of respondents who provided additional information about other factors they considered constraints in relation to lack of feed and good quality feed. Sample size n = 17.

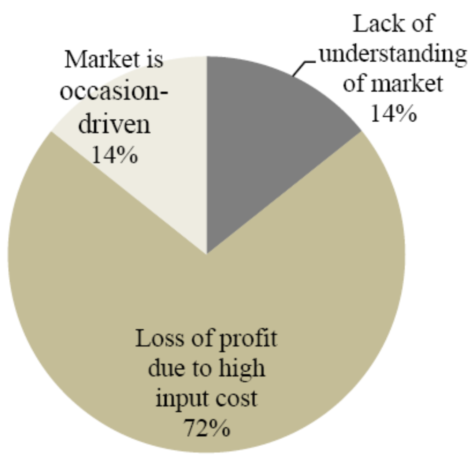

Figure 3. Proportion of respondents (n = 7), who provided additional information about other factors they considered constraints in relation to lack of market.

For the Abandoned and Potential Adopters, lack of capital could explain why they are not currently practicing cage aquaculture. When asked if they were interested in resuming the business, all 20 respondents (100%) in the Abandoned group (including 10 farmers who have abandoned pen fish farming) were interested in resuming cage aquaculture if they had capital. The pen farmers were interested in adopting cage aquaculture but not pen farming because they had received some training in cage aquaculture and found it more desirable than pen aquaculture.

Lack of extension was ranked as the second most important constraint by Adopters with a mean of 3.0 (Figure 1). The Fisheries Commission ranked lack of extension as very important (4), however, both the Abandoned and Potential Adopters rated lack of extension or lack of information (for Potential Adopters) as a slightly unimportant constraint. In contrast, the regional and district fisheries officers ranked lack of extension quiet low with a mean of 1.6. This is probably because the regional and district fisheries officers felt they were doing their best doubling as extension officers in addition to their assigned duties.

Apart from lack of capital and lack of extension, respondents ranked all other constraint as slightly unimportant (mean rank of 2.2 or lower). The only exceptions are cage destruction by storms which was ranked higher by Abandoned (mean rank of 2.7) and theft which was ranked 4 and 3.4 by the Fisheries Commission, and regional and district fisheries officers respectively. Cage destruction by storms was ranked as slightly important because 50% of the cage farmers who had quit the business did so because their cages had been destroyed by storms. Theft was probably ranked high by the Fisheries Commission, and the regional and district fisheries officers because of individual reports by some farmers but it appears that once capital is available to hire security personnel on farms, the problem of theft is easily dealt with.

Interview results shared some similarities with survey result in terms of lack of extension being a major constraint in cage fish farming. Whereas all three interviewees mentioned lack of extension specifically, only one mentioned lack of capital as a constraint. Interestingly, all three interviewees stated lack of knowledge in cage aquaculture as the main constraint. However, this did not show in the responses of Adopters and Abandoned considering that 71% and 85% respectively, said they had had cage aquaculture training. On the other hand, lack of knowledge may be a constraint for Potential Adopter evident by a small number (30%) with training in cage aquaculture.

Opportunities that can be exploited

In response to whether they would be able to market their produce if they could expand their production above current level, 95% of Adopters (n = 37) responded yes, suggesting a potential to expand the aquaculture industry through cage aquaculture. Farmers also appear to be making profits judging from the fact that 96% of all Adopters said they would recommend cage aquaculture to potential farmers, with more than half of them (57%, n = 44) recommending cage aquaculture on the basis of its profitability.

Another opportunity that can be exploited to expand production was evident when 79% of Potential Adopters said they were interested in starting cage aquaculture on the Volta Lake. Some fisher folk in the group indicated they could hardly wait to start due to the advantage of getting fish all year round compared to the seasonality of fishing. Additionally, 84% and 100% of Potential Adopters and Abandoned respectively, responded yes when asked whether they were interested to start or resume cage aquaculture if constraints are removed. The prospects of making profit was a strong indication why both Abandoned and Potential Adopters were interested in cage aquaculture but they also indicated that they found management of cages relatively easy.

We also learned through the interviews that a private enterprise has started producing floating feed for fish farmers in Ghana. Hopefully, this should ease the burden of high feed cost on farmers especially if local ingredients are used. We expect locally produced floating feed to be cheaper but the price and quality of locally produced floating feed will need to be verified in future studies before a definite advantage for cage aquaculture development can be ascribed.

In exploring the possibility of cage fish farmers being able to access loans from banks and other financial institution, we learned that some banks have had unpleasant experiences with fish farmers in the past and indeed were skeptical about future loans to fish farmers. Nevertheless, some institutions were willing to provide loans to fish farmers if they had guarantors, property collateral, and the institution had sufficient knowledge about the entire project. There were also opportunities for groups to access micro-finance with relatively less stringent criteria. Our findings are consistent with that of another study by Hishamunda and Manning (2002) who investigated the role of banks in aquaculture development in six countries in Sub-Saharan Africa (Cote d'Ivoire, Madagascar, Malawi, Mozambique, Nigeria, and Zambia) and found that banks were skeptical about giving fish farmers loans because of past failures but there still existed opportunities for acquiring loans if farmers had a convincing proof of success.

Certain government initiatives were also identified as avenues to improve cage aquaculture in Ghana. Results from the survey revealed that some interested individuals had received training in cage aquaculture organized by the government and were awaiting cages from the government to commence business. This is probably a part of a "Youth in Agriculture" proposal by the Ministry of Agriculture which we learned about during the interviews. Finally, our study also revealed that limited government supported microfinance and small loans centers were in operation in Ghana and could be accessed by fish farmers.

TRAINING

Lack of extension (or lack of information) was ranked high as a constraint by all respondents except regional fisheries officers. For adopters reporting lack of training as a constraint, one way to ease this constraint and ensure that they do not eventually abandon cage culture because of lack of knowledge is to provide training. We identified 15 such farmers who would benefit from immediate training. In February 2011, these farmers, along with three project personnel were sponsored by KNUST to attend a one-day workshop on Low Volume-High Density (LVHD) cage systems. Ten of the farmers made it to the workshop taught by Ms. Karen Veverica of Auburn University and held at Crystal Lake Farms at Anum-Boso on the Volta Lake. There were opportunities to learn important basic lessons in fish farming such as feeding and understanding feed conversion ratios, as well as specific hands-on experiences with LVHD cage systems.

CONCLUSION AND RECOMMENDATIONS

Our study suggests that the main constraint in cage aquaculture in Ghana is the lack of capital to purchase input such as feed. While lack of capital prevented farmers who have abandoned cage aquaculture from resuming, the constraint also barred potential adopters from starting cage aquaculture even though they showed a high interest in the business. In addition, farmers appeared to have knowledge in their operations but it seems the knowledge is inadequate and they could use more extension services.

In light of these results, our preliminary recommendations are that the Fisheries Commission should work with the financial institutions to help determine farmers' ability to repay loans and guarantee loans made by the financial institutions. In the long run, aquaculture could be made more attractive and competitive by subsidizing feed cost for small-holders, especially if quality floating feed is produced locally. It would seem appropriate to provide subsidies for some of the most expensive inputs for aquaculture since farmers in crop production receive similar subsidies on fertilizers and other inputs. Also, there is a need for a more specialized aquaculture extension service accessible to farmers to help with technical issues built on the model of agricultural extension services in Ghana. Farmers who cannot afford private extension services would greatly benefit from such a program especially if this is a cheaper alternative.

ACKNOWLEDGEMENT

Collaboration with the Fisheries Commission and Water Research Institute of Ghana ensured the integrity of data collected and the cooperation of participants. We thank all participants of the surveys for their cooperation. We also thank all Assembly men and opinion leaders in the regions surveyed who assisted us with contacting participants and language translation. We are grateful to Yaw Ansah for his assistance with questionnaire administration.

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Assessment of AquaFish CRSP Technology Adoption and Impact

Technology Adoption and Policy Development/Study/09TAP05OR

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*[**MT Comment:** The AquaFish CRSP Management Team has offered named individuals and parties in this report an opportunity to respond to statements made by the authors. Responses have been inserted within brackets using italicized font. Full rebuttals can be requested from the MT by writing to aquafish@oregonstate.edu.]*

INTRODUCTION

This report presents the results of the activities carried out by the investigation "Assessment of AquaFish CRSP Technology Adoption and Impact/ 09TAP06OR". The objectives of this investigation are:

1. Further develop "minimum data" (MD) methods and software for assessing the adoption and economic, environmental, and health impacts of agricultural technologies.

2. Train AquaFish CRSP project personnel to use MD methods and software in current and possible future investigations.

3. Collaborate with AquaFish CRSP project personnel to assess impacts of selected technologies, using sustainability indicators such as fish farm and trader income, environmental quality, human health, gender, and other social outcomes.

METHODS

The TOA-MD Model

This investigation uses a recently developed methodology for impact assessment and that will be referred to as "minimum-data tradeoff analysis" (TOA-MD). This methodology is based on the conceptual model underlying the development of "Tradeoff Analysis" (TOA) (Antle et al. 1998; Stoorvogel et al. 2004) and the "minimum data" methods developed by Antle and Valdivia (2006). The TOA-MD model is a unique simulation tool that uses a statistical description of a *heterogeneous farm population* to simulate the proportion of farms that utilizes a baseline system (e.g., farms without ponds) and the proportion of farms that would adopt an alternative system (e.g., integrated agriculture-aquaculture systems) within defined *strata* of the population. The TOA-MD model predicts an adoption rate for each stratum of the population, using the assumption that farmers are economically rational and adopt practices that are expected to provide the highest economic return. Accordingly, this predicted adoption rate should be interpreted as the proportion of farms for which the alternative systems practices are *economically feasible*. If there are institutional or behavioral factors that constrain adoption – such as limited access to financial resources, or risk aversion – then this predicted adoption rate is likely to be an upper bound on the actual adoption rate that is observed. Further analysis may be required to incorporate the effects of such constraints. Based on the predicted rate of adoption, the TOA-MD model also simulates economic, environmental and social *impact indicators* for the sub-population of adopting farms, the sub-population of non-adopters, and the entire population.

TOA-MD model uses statistical relationships between technology adoption and the environmental, economic and social outcomes, to simulate impacts of adoption. Impacts are defined as population means, or as the proportion of the population above or below a threshold, e.g., a poverty line or a nutritional requirement. Economic research shows that taking into account the inter-relationships between adoption and outcomes is critical to obtain accurate estimates of impact. This fact has important implications for project design and data collection as it is discussed in the Conclusions of this report.

Another unique feature of the TOA-MD model is its parsimonious, generic structure, which means that it can be used to simulate virtually any farm system. One virtue of this model design is that, unlike many large, complex simulation models, it is easy to address the inherent uncertainty in impact assessments by using sensitivity analysis to explore how results change with the relatively small number of model parameters. The TOA-MD model is programmed in Excel, and is easy to learn and use. Further details about the TOA-MD are available at http://tradeoffs.oregonstate.edu.

LIST OF TASKS AND COMPLETION DETAILS:

Adapt TOA-MD for impact assessment analyses

The TOA-MD software was updated to incorporate an aquaculture component. This updated version is also capable of modeling environmental and health impacts. The model's documentation was updated. The TOA-MD model in MS Excel was tested using a case study of adoption of Integrated Agriculture-Aquaculture in Malawi. This case study was used to prepare the materials to introduce the approach and software at the Project Meeting in Seattle (October, 2010).

Prepare the First Project Meeting – Seattle, WA (October 4 - 7, 2010)

Although the Seattle Project Meeting is the investigation #3 of this project (see report for this investigation for more details), some activities related to investigation #2 were carried out:

- AquaFish CRSP projects and technologies under development were reviewed using project reports and direct communication with key host countries' investigators. The objective was twofold, first to get to know and understand current project's activities and second to try to elaborate a working example using data from one of these investigations to be used at the Project meeting.

- We contacted previous projects (e.g., in Peru). They indicated that they had data, and indicated a willingness to collaborate, but we were instructed by the project director not to work with previous investigations.

  ***[MT Response**: Communication on this matter was between John Antle and CRSP staff, and did not directly involve the director. The statement is further erroneous because staff encouraged ex-post assessment, including the use of older Aquaculture CRSP countries, as long as work was conducted in currently active AquaFish countries. During the proposal writing stage prior to approval of this project, staff informed proposal proponents that Peru would be difficult to include because it was not one of the countries that USAID had approved for AquaFish work, and would therefore entail an additional USAID country review and subsequent additional delays, with a possible negative outcome.]*

- We followed up a conversation we had with Mr. So Nam (Cambodia) and Mr. Le Xuan Sinh (Vietnam) at the annual meeting in San Diego (February, 2010). Both of them agreed to provide data to construct an example to be used at the Project meeting. However by the end of August 2010 they both mentioned that they were over-committed with work and therefore they couldn't provide data to us. We also communicated with Eladio Gaxiola (Mexico) who also mentioned that they could provide data, however his project wanted to involve an economist (Dr. Rafael Figueroa) to work with us. After several unsuccessful attempts to contact Dr. Figueroa (he didn't return phone calls or emails) we decided to use data available from a study conducted by the World Fish Center in Southern Malawi (Dey et al., 2010).

  *[**Maria Haws, University of Hawaii at Hilo, excerpted response:** First, he does not spend much time discussing the Mexico and Nicaragua projects despite the efforts and time our HC counterparts devoted to working with him. That is fine if our project data was not adequate to use for his modeling efforts. He does give the impression however, in his discussion of the involvement of Dr. Figueroa that our team was not willing to help him and that Dr. Figueroa ignored his communications. This is not in fact the case. Dr. Figueroa was unable to attend the Seattle meeting due to health issues, but Eladio Gaxiola facilitated communications on a regular basis and also took the time to attend the meeting.]*

  *[**Eladio Gaxiola Camacho, Autonomous Universidad de Sinaloa, excerpted response:** After the CRSP meeting on February 2010, in San Diego, California, USA, I invited Dr. Jorge Rafael Figueroa Elenes - prestigious economist by the UAS University who participated in the first stage of CRSP/UAS Project. 2004/2006- so he could attend the invitation for the Seattle workshop which would take place in October of the same year, at the end he accepted. A couple of months before the workshop (August 2010) we, Dr. Figueroa, Dr.Roberto Valdivia and I, had a simultaneous phone conversation. Dr Valdivia explained the main idea of The TOA-MD model and the visit was planned. On August 19th 2010 Dr. Figueroa received the invitation letter signed by Dr. Antle, Dr. Valdivia and Dr. Buccola. Otherwise, because of personal issues Dr. Figueroa couldn't attend the workshop and this was informed to Dr. Valdivia. Then, in order to execute this responsibility I decided to be there personally.]*

Dey's data was analyzed and along with other secondary data we constructed an application of the TOA-MD for impact assessment for the case study "Integrated Agriculture-Aquaculture in Southern Malawi". This application was used in the Seattle's Project meeting to introduce participants to the concepts of impact assessment, the TOA-MD model and software.

During the Seattle's Project Meeting, we presented details about the methodology and model which involves three steps: Design, Data acquisition and analysis. Participants from each project developed a Design (first step) for one or more of their investigations. We then interviewed each host country PI and participants to identify investigations that were suitable for impact assessment analysis and data availability for analysis. Given the time constraint (analysis should be completed by September 1st, 2011) and the fact that most of the investigations did not have funds for additional data collection for impact assessment we identified three investigations to be used as case studies for impact assessment (see annex 1 for a complete detail of all the projects activities and their suitability for IA). Each US PI and HC PI identified one member of their team to lead the impact assessment analysis (Impact Assessment Leader, IAL). The three investigations were:

- Snakehead Culture in Cambodia, IAL So Nam
- Snakehead Culture in Viet Nam, IAL Le Xua Sinh
- Pond Aquaculture in Hubei and Hainan Provinces of China, IAL Zexia Gao

The IALs agreed to assemble data needed for the impact assessment case studies and submit progress reports (see the template of the Personal Services Contract in Annex 3).

By the end of the project meeting all the participants had learned key concepts for impact assessment, the TOA-MD approach and concepts as well as a hands-on experience using the software running and analyzing the Malawi example.

It is also important to mention that we invited Charles Ngugi to the Project Meeting, but he was not able to attend. However, Kwamena Quagrainie (who attended the meeting) suggested that Ngugi's investigations in Kenya had data suitable for impact assessment and they were interested in applying the TOA-MD using their data. Roberto Valdivia was planning to be in Nairobi, Kenya in November 2010 for other work, and a meeting was planned with Charles Ngugi. However, Charles Ngugi didn't attend the meeting and he never returned subsequent phone calls or emails. We contacted the US PI, Dr. Quagrainie and informed him about the situation and the collaboration therefore was not implemented.

*[**Kwamena Quagrainie, Purdue University, and C. Ngugi, Ministry of Fisheries Development, Kenya, excerpted response:** It must be noted that the impact assessment team had reviewed all the Aquaculture CRSP investigations prior to the Seattle meeting and had selected potential investigations to do impact assessment, and none of the investigations from the Purdue project was selected. However, Kwamena Quagrainie who was at the meeting in Seattle suggested that an investigation on fingerling production technology in Kenya would be suitable for impact assessment because Kenyan fish farmers involved in that technology kept good farm records. The farm-level data required for the TOA-MD model such as such as pond sizes, yield, output, inputs, prices etc. were available from farmers so it required some arrangement between the impact assessment team and the Kenya PI, Charles Ngugi to collect the required data. From further discussions between Kwamena and Roberto, it became known that Roberto was travelling to Kenya in November 2010 on another assignment and that he would like to meet Charles to discuss data needs for impact assessment for Kenya's investigation. In Kenya, it appears Roberto's main purpose was for some work at the International Livestock Research Institute (ILRI) which had a campus outside Nairobi, and he indicated he had only one day to meet Charles, although he would be in Kenya for at least a week. Unfortunately, Charles was unable to make it to the ILRI campus for the meeting because of prior commitments, and that meeting was never rescheduled. We think that given the importance of the impact assessment investigation and the fact that Roberto spent at least a week in Kenya, the planned meeting with Charles should have been rescheduled and not considered of a lesser importance with a 'make-it' or 'lose-it' type schedule. While in Kenya, Roberto did not follow up with Charles though he had Charles's cell phone number, and Charles had no contact information for Roberto in Kenya, except the knowledge that Roberto was going to do some work at the ILRI campus.]*

Provide technical support to IALs so they can collect data and begin to implement the analysis

We maintained communication with the IALs and responded to their questions regarding data collection, system descriptions, and model's data requirements. We met them at the Shanghai meeting (April, 2011) and followed up with them the following months.

As part of their contracts, IALs agreed to the following deliverables:

1. System Description
2. Data Templates
3. IA analysis

Impact Assessment Leader	Country	First deliverable	Second deliverable	Third deliverable
So Nam	Cambodia	Submitted not in acceptable form (04/12/2011)	Submitted in un-usable form (04/12/2011)	Could not be completed due to unusable data
Le Xua Sinh	Vietnam	Submitted not in acceptable form (04/12/2011) Re-submitted (07/18/11)	Submitted in un-useable form (3/12/11).	Could not be completed due to unusable data
Gao Zexia	China	Submitted ((01/28/11)	Submitted in un-usable form (April-July, 2011)	Could not be completed due to unusable data

In the case of So Nam and Le Xua Sinh we met with them at the Aquafish CRSP Annual meeting in Shanghai (April 18, 2011). They showed us some of their data which were not in acceptable form for IA analysis. We explained them that they needed to do additional work so the data can be used for impact assessment modeling. Their response was that they are overloaded with work and they could not do further work for this investigation.

*[**Le Xuan Sinh, Can Tho University excerpted response**: Resubmissions were done in July to Prof. John Antle and Steve Buccola in Sep (and also to So Nam) but no comments on it received.]*

*[**So Nam, IFReDI, excerpted response:** We (2 IFReDI staff: Ms. Hap Navy and Mr. Tray Bunthan and myself) spent 32 days to collect and compile both existing data and additional field data, and conduct training how to collect the data needed for this assignment.]*

*[**Gao Zexia, Huazhong Agricultural University, excerpted response:** A. It is difficult to calculate how many hours or days did you and your team spend collecting and compiling data for this investigation. I would say at least two months for me in total. Our team, one month. B. there were five staff members participated in these activities. C. I did do some training for my team member on how to collect the data needed by meeting, emails and phones.]*

In the case of Zexia Gao, we exchanged numerous emails, phone and skype calls to clarify her data (with the assistance of graduate student Lin Qin). The data she sent had many problems and unresolved issues and she was not able to address the problems. After a great deal of effort she sent us the raw data. We then could see the problems with the data. These data were supposed to be collected using a survey instrument (for which we sent her a list of key questions to ask), however the data showed that many observations for key variables had the same value. We asked her about this issue and the response we got was:

"I just got the information from Lin and asked me to explain some questions to you. As to our questionnaires, most were collected from the training conference for fish farmers. The farmers had no idea about the variable cost or fixed cost. They don't know the exactly money for these cost. So, just several farmers wrote down these two costs. Considering this situation, we asked them to write down the net return directly, which farmers maybe more clear because the net return is the most important thing they care about.

As to the some extent similar data, because these farmers do the questionnaires together. Actually, for each farmer, they don't know the exactly number of their net return, we gave some hint to them, like how much the net return for each mu unit pond, then you can have an estimate according to your farm size. Because they are not sure, so they maybe discuss and then had the similar number. For this situation, we can not control."

This clearly shows that the data collected in this investigation used a flawed survey methodology and thus were not suitable for IA modeling. It is fair to say that Zexia had a great interest in conducting an impact assessment analysis and she made the efforts to gather the data, but the lack of an economist in her team knowledgable about survey methods was one of the major limitations to properly conduct this analysis.

***[James Diana, University of Michigan, excerpted response:** The data collection for this study was flawed, but I would blame the design of the project for the flaws, not the people doing the surveys. I have overseen the completion of many social surveys under CRSP funding, and the most important part of such surveys is the design of the survey instrument. In this particular case, the people involved were given rather unclear descriptions of the methods of survey, and as a result, ALL of them were unable to collect meaningful data. I believe that this problem stemmed from a flawed survey instrument and inadequate instructions to the people conducting the survey.]*

In addition, to augment the economic analysis for China, graduate student Lin Qin prepared a research paper for the course on "Sustainable Development" taught by PI Antle in Spring quarter 2010. However, due to the problems with the data discussed above, this work could not be completed successfully.

Market Surplus Analysis

We explored the possibility to conduct a market surplus analysis using the case studies of Vietnam, Cambodia and China. We faced the same issues regarding data availability as described above. No useful data was received from the IALs. See the annex for more details.

Publications and Reports

- **IAL's System description reports (see the annex)**
    - So Nam:
    - Le Xua Singh:
    - Gao Zexia:

- **Publications**
    - Antle, J. & R.O. Valdivia, 2011. "Methods For Assessing Economic, Environmental And Social Impacts Of Aquaculture Technologies: Adoption Of Integrated Agriculture-Aquaculture In Malawi". Presented at the 9th Asian Fisheries and Aquaculture Forum).

CRITICAL LIMITATIONS TO SUCCESSFUL COMPLETION OF IMPACT ASSESSMENTS

A number of critical events limited the successful completion of impact assessments. Here we identify and discuss them:

- **Delay in project approval.** The project proposal was for a 2-years of work, anticipated to begin in late 2009 or early 2010 at the latest. In fact, due to unexplained delays in submission of the project proposal to USAID by the AquaFish project management, the project was not approved until June 2010. PI Antle repeatedly questioned the delays and warned AquaFish leadership that these delays would have dire consequences for the ability of the IA team to complete its work.

  [MT Response*: The statement that the Research Discovery/Impact Assessment (RD/IA) project was not approved until June 2010 is not correct. The final proposal was approved by the Management Team on April 20, 2010, after an external peer review process was completed and USAID and EPAC input was received. Approval was communicated to the authors on April 20, 2010. The subcontract with MSU was signed by OSU on May 5, 2010, and by MSU on May 19, 2010. Further, delays in proposal approval were not the result of USAID review, but rather due to the proposal's shortcomings for which additional revisions to the budget and narrative were needed in order to meet AquaFish CRSP proposal submission standards.*

  AquaFish leadership did not receive numerous communications from John Antle warning of dire consequences for the ability of the IA team to complete its work. Ford Evans received one email from Steve Buccola on March 22, 2010, expressing concerns over delays; Ford Evans responded on March 22, 2010, with reviewer comments that still needed to be addressed. It was made clear to the RD/IA team that the start date of the proposed project was to be back-dated to January 1, 2010, as indicated in the February 8, 2010 revision of the proposal. AquaFish's commitment to the proposed work was further demonstrated by providing travel support for Antle and Valdivia to the March 2010 Annual Meeting in San Diego with the understanding that these charges would be transferred to the MSU subaward once it was in place.

  In Summer 2011, after applying to USAID for a no-cost extension, the AquaFish CRSP Management Team offered extensions (NCE) to each core research project extending the end date for up to approximately 20% of their investigations. Under the NCE, the end date would be moved from September 29, 2011, to December 31, 2011. Steve Buccola, acting as the projects Lead PI, requested that the Research Discovery investigation be extended and not the Impact Assessment investigation subcontracted to MSU.]

  One of the most severe consequences of this delay was that the project had not been approved at the time of the March, 2010 Annual Project meeting. At that time, the IA team met with investigators and planned travel to meet with them and plan data collection in June 2010 when the IA team had made plans for and had the opportunity to carry out these activities in a timely manner to facilitate planning for data collection. However, because the project was not approved, it was not possible for the IA team's travel to be approved. As a result, it was not possible for the IA team to carry out important collaborations with other project investigators in a timely manner before the October 2010 project meeting in Seattle.

  [MT Response*: The originally submitted proposal did not include international travel for the IA team and only included international travel for one non-host country colleague to fly from the Netherlands to the US to collaborate with the IA team. Upon review, it was suggested that the authors consider including trips to visit select HC participants. At no time did the authors* *indicate that this travel was essential to the success of the project. Further, both Antle and Buccola approved the final proposal, dated April 20, 2010, which included only one international trip in 2010 which was taken by the RD team to collaborate with Asia project investigators.]*

***[Christine Crawford, EPAC member, University of Tasmania, excerpted response**: It is also my understanding that there was no need for the commencement of the project to be delayed. It was approved in early 2010 and Antle was informed that there would be some delay in receiving funding because of contracting administration in USAID. Antle and Buccola were given advance funds to attend the annual meeting in San Diego and they were given permission to piggy back the new projects on to the original project of Buccola.]*

- **Delays in implementation of other Impact Assessment Activities.**
  During the Annual Project Meeting in March, 2010, the IA team was informed that two projects were being provided additional funds to collect data for impact assessments. The IA team attempted to coordinate with these project PIs. However, because of delays in funding these activities, this coordination failed, as noted above. At the time that data collection had to be completed to implement analysis by the IA team (early 2011), none of these activities had been implemented.

  ***[MT Response:** It is inaccurate to say that funding was delayed for the "Add On" projects proposed by both University of Connecticut and North Carolina State University. Submission deadlines for "Add On" proposals were flexible, placing responsibility on US Lead PI to submit proposals in a timely manner and to formulate work plan schedules to ensure that the proposed work was completed before the grant end date of September 29, 2011.]*

- **Attempting to do Impact Assessment "After the Fact."**
  One of the fundamental principles of impact assessment is that IA must be integrated into project implementation, to facilitate appropriate data collection. The fact that this was not done in AquaFish projects is a major explanation for the lack of data needed to carry out impact assessments. The concern over this issue is the reason why the IA proposal emphasized that it would only be possible to carry out impact assessments for those investigations which had suitable data. Unfortunately, what the IA team found was that NONE of the projects had suitable data for impact assessment using the TOA-MD methods or conventional market surplus methods, despite claims by project investigators that data were being collection for impact assessment.

  ***[MT Response:** It is misleading to suggest that AquaFish CRSP does not have impact assessment designed into the program. In 2007, at the onset of this CRSP and in consultation with USAID, metrics were developed for the AquaFish CRSP that tracked the program's four development themes (referred to as the Development Themes Advisory Panel [DTAP] metrics). These metrics are reported on annually by the DTAP Lead Coordinators. AquaFish CRSP is also required to report semi-annually to USAID on impact assessment metrics under the USAID reporting framework. Additionally, a monitoring and evaluation framework was built into the original program description in 2006; then updated and received USAID's approval in 2007.*

  Per their signed subcontract, the Impact Assessment (IA) team planned to assess impacts of AquaFish CRSP technologies "after the fact" with TOA-MD methods and were thus aware at the outset when they initially submitted their proposal that the type of impact assessment data that they required may not already be integrated into AquaFish CRSP projects.

  Further, at the time that this proposal was being developed, the authors had access to publically available documents on the AquaFish CRSP webpage – such as Annual Reports and

Implementation Plans – to allow them to become familiar with investigation-specific goals and methodologies. During the course of the project, the authors (project PI's) had access to a wealth of data including all tabulated DTAP metrics, USAID indicator metrics, and other databases (e.g. training) and reports].

- **Lack of economics expertise in AquaFish projects.**
  A related principle is that economists with IA skills must be part of the project teams. The lack of such individuals is evident in AquaFish projects; see for example the above discussion of the problems encountered in the data collected in China. The clear lesson is that in future projects, these shortcomings must be remedied if successful impact assessments are to be achieved.

  ***[Robert Pomeroy, University of Connecticut, excerpted response**: Two of the six host country investigators are economists (Sinh from Cantho U with a PhD from Australia National U and Hap Navy with a MS from the U of the Philippines). I have a PhD in Ag and Res Economics.]*

  ***[James Diana, University of Michigan, excerpted response:** To complete my response to Dr. Antle's final report, I would just like to emphasize that the personnel we have working on our project in China have completed a number of surveys in the past, and with adequate instruction and care given to the design of the survey instrument, we have had much success in these surveys. We have published several of them in peer reviewed journals, and never had complaints about the quality of the work done there.]*

- **Lack of cooperation from scientists in other Investigations.**
  This problem follows from all of the preceding difficulties. Because of the late start of the IA investigation, scientists in other projects had little time to dedicate to IA activities, and did not take ownership of doing IA. US PIs apparently were not willing to instruct their teams to commit requisite time to IA. Moreover, because the IA activities were add-ons, after the fact, these problems were compounded: project personnel rightly felt that they were being asked to do more work than they had agreed to when they joined the AquaFish project; they perceived IA as work that they did not budget either time or money to complete. Finally, since economic expertise was lacking in most projects, doing IA was even more of a burden because project scientists did not have the expertise and felt it was not a good use of their scarce time, and did not attach a high value or priority to the IA activities.

  *[**Joseph Molnar, Auburn University, excerpted response:** The instruments and data collection procedures were burdensome, imprecise, and not well-explained.]*

  ***[Robert Pomeroy, University of Connecticut, excerpted response**: This puts the blame on the US PIs for Antle's inability to get results. I, for one, instructed and worked with So Nam and Sinh to get this work done.]*

  *[**Maria Haws, University of Hawaii, excerpted response:** …I take exception to his comment that the CRSP Principal Investigators did not engage in the project. All of us spent considerable amounts of time meeting with him and the other related researchers at several meetings. I believe that we collectively did our best to assist him despite a general perception that his model would be of little use to practitioners in the field. I personally did my best to assist him, and I observed that my fellow Principal Investigators did the same. We also helped coordinate with our HC colleagues. Given the poor outcomes of his work as presented in his report, I feel that my time and that of my HC colleagues was not particularly well spent trying to assist Dr. Antle.]*

***[Christine Crawford, EPAC member, University of Tasmania, excerpted response**: The data requirements for the model were a huge impost on the workloads of the HC researchers. Instead of Antle and his team collecting and collating the data required for the modelling, they expected the HC to provide this information in the format required, which was very time consuming and in addition to planned workloads. The Personal Service Contracts that Antle developed with researchers in Cambodia, China and Vietnam required a large amount of work for a paltry compensation of $3300. It is not surprising that this requirement for additional work towards the end of the projects, which was not well understood by the researchers, was not completed.*

The workshops run by Antle and Buccola in San Diego and especially in Shanghai were not well organised. As a consequence, the HC researchers struggled to understand the methodology and the input that was required from them. As noted in my EPAC report in May 2011 "There was clearly still considerable confusion amongst HC participants about the methodology and data requirements of the project." Importantly, the researchers did not understand the relevance of the additional work that they were being asked to complete.]

CONCLUSIONS AND LESSONS LEARNED

This investigation achieved several of its goals, but did not achieve the ultimate goal of implementing impact assessments for some AquaFish investigations. The goals that were achieved were:

- Improvement of the impact assessment tool, TOA-MD, to be more useful for analysis of aquaculture projects
- Availability of TOA-MD model with documentation, suitable for application to aquaculture systems, on an improved web site
- Training of AquaFish scientists in the use of TOA-MD
- Identification of AquaFish investigations that could be assessed using TOA-MD with appropriate data
- Application of TOA-MD to an aquaculture case study to demonstrate its usefulness.
- Creation of a foundation on which future successful impact assessment of AquaFish or other aquaculture research projects could be built, if an appropriate IA strategy is followed, as discussed above.

However, for the reasons presented above, this investigation did not achieve the goal of implementing impact assessments due to the delays in project approval and funding, lack of data, time, and willing collaboration from project scientists. Except for the delays in project approval, these problems all can be traced to the attempt by the AquaFish CRSP to organize impact assessments "after the fact," that is, after other projects had been designed and largely implemented. The obvious lesson to be learned is that to be successful, impact assessments must be designed into projects from the beginning, and made an integral part of projects with appropriate time and budgets to collect data and complete analysis.

***[MT Response:** As stated earlier, it is misleading to suggest that AquaFish CRSP does not have impact assessment designed into the program. Please see previous comments under the section "Attempting to do Impact Assessment 'After the Fact'.]*

A good example of how impact assessment could be successfully implemented is provided by the last round of the IPM CRSP, where a dedicated impact assessment project was included as part of the overall CRSP design. Another example is collaboration now in progress between the WorldFish Center and the Tradeoff Analysis Team at Oregon State University. In this collaboration, WorldFish impact assessment scientists are being trained to use TOA-MD and apply it to assess impacts of aquaculture research being done at the WorldFish Center. By incorporating impact assessment into ongoing research projects with suitable training of project scientists and collection of appropriate data, successful impact assessments will be carried out.

ANNEX 1: AQUAFISH CRSP IMPACT ASSESSMENT USING TOA-MD AND RELATED METHODS: SEATTLE MEETING SUMMARY AND PLANS FOR 2010-2011

The Impact Assessment Investigation (henceforth, IAI) led by J. Antle and R. Valdivia met with participants at the Seattle meeting October 4-7, 2010. Given the time and resource constraints of the present IA investigation, data for implementing an IA must be available within the next 5 months. As noted in the IA investigation proposal, it was unlikely that all projects in the AquaFish CRSP would have data available to enable an IA during the 2-year time span of this investigation. This likelihood was further reduced when the IA investigation start date was delayed until mid-2010.

At the Seattle meeting, participants developed Designs for IA of one or more of their projects' investigations. All of the Designs developed at the meeting could be evaluated with appropriate IA methods if suitable data were available. However, as anticipated, in several cases data will not be available within the window required for IA implementation during 2011. In some cases, this is because the IA design was not developed at the beginning of the investigation, and in other cases it is because the investigation is in an early stage of implementation and will not be able to generate suitable data within the next 5 months.

Although several projects do not have data available for implementation of IA using the TOA-MD or related market surplus methods at the present time, all of the participants expressed interest in utilizing the methods in future AquaFish CRSP activities and related research.

University of Arizona

Wilfrido Contreras and Pablo Gonzalez developed Designs for possible IA of aquaculture systems which addressed water quality issues. However, data are not available to implement IAs of these systems. They both expressed interest in using the TOA-MD methods in future research. No further activities are planned for this project.

*[**Wilfrido Contreras-Sanchez, Universidad Juarez Autónoma de Tabasco, excerpted response:** We (Pablo and myself) met with them and provided all the information generated and agreed that the information from our project didn´t fit the type of information needed to conduct the study that the team was looking for.]*

North Carolina State University

Evelyn Ayson and Remedios Bolivar attended the Seattle meeting, and prepared a Design for IA of reduced feeding strategies they are studying in the Philippines. They also discussed the plans for a survey to be conducted with funding from a supplemental IA grant from USAID. It was agreed that this survey could provide an opportunity to obtain data for an IA of reduced feeding strategies. John Antle agreed to contact the US Project PI Russell Borski to discuss this possibility.

University of Michigan

Zexia Gao and Vu Cam Luong attended the Seattle meeting. Gao prepared a Design for assessing impacts of Best Management Practices for Chinese aquaculture systems, and Luong prepared a design for the Tri An reservoir. It was agreed that survey data collected in China, and that are being collected in December 2010, would provide the basis for an IA study. A PSC will be prepared for Gao's collaboration with the Antle-Valdivia IA investigation. The Tri An reservoir investigation presents an interesting case for study of management of a common property resource, but data are not available to implement an IA at this time.

University of Hawaii
Eladio Gaxiola and Erick Sandoval attended the Seattle meeting and presented a Design for IA of estuary management. However, data are not available to implement an IA at this time. Erick expressed interest in using the TOA-MD methods in other research he is doing.

Auburn University
Gertrude Atakunda and Khalid Salie presented a Design for IA of an aquaculture project in Lake Victoria. However, data are not available for an IA at this time. However, Gertrude expressed enthusiasm about using the TOA-MD methods in related research, and Khalid Salie also noted his interest in using the TOA-MD model in his PhD dissertation project.

University of Connecticut
So Nam and Le Xuan Sinh presented Designs for IA of management practices to improve the production of snakehead in Cambodia and Vietnam. Survey data and on-farm trial data are available and more data will be collected in early 2011. It was agreed that PSCs would be prepared for Nam and Sihn to implement these IAs.

Purdue University
Steve Amisah and Sebastian Chenyambuga presented Designs for IA of agriculture-aquaculture systems in Ghana and Tanzania. Both cases would be useful applications of the TOA-MD methods. These investigations are at early stages, so data are not available to implement IAs now, but the methods they learned at the meeting will allow them to develop data suitable for IA of the investigations in the future. In addition, US PI Kwamena Quagrainie attended the meeting, and proposed that an IA of a fingerling production technology developed by the ACRSP could be carried out. He will discuss this possibility with Charles Nguki and will communicate with Antle and Valdivia as soon as possible. Valdivia could meet with Charles Nguki in November to further discuss data needed to implement an IA of this technology in Kenya.

ANNEX 2: PERSONAL SERVICE CONTRACTS FOR CAMBODIA, CHINA AND VIETNAM

The following is the format of the PSCs prepared for the three investigations identified at the October 2010 Project Meeting in Seattle.

Terms of Personal Service Contract – [Name of Contractee]

Tasks to be Performed

1. Prepare a brief document describing the baseline system (System 1 in the model terminology) currently being used by farmers in Hubei and Hainan Provinces, and describing the system using best management practices for integrated waste management (System 2 in the model terminology). This document should follow the structure of the TOA-MD data template (crop subsystem and activities; aquaculture subsystem and activities; farm household; etc).

2. Using survey data that has been collected in these provinces, compute the statistics needed to parameterize the TOA-MD model for the baseline system (System 1). Using survey data collected from the ponds now using the best management practices for waste management, compute the statistics needed to parameterize the TOA-MD model for the this system (System 2 in the model). Prepare a brief document providing documentation of the survey data used.

3. Collaborate with the IA team to run the model, interpret the results, and carry out sensitivity analysis to key parameters.

4. Collaborate with the IA team to prepare a project report on the data, the analysis and results.

Task Schedule and Deliverables

- Task 1 completed by February 1, 2011.
- Task 2 completed by April 1, 2011.
- Task 3 completed by June 1, 2011.
- Task 4 completed by August 1, 2011.

Deliverables for tasks 1 and 2 will be submitted via email to John Antle with copies to Hillary Egna. Deliverables for Tasks 3 and 4 will be considered complete when the Task 4 report is completed and submitted in collaboration with John Antle.

Compensation

We propose paying you $3,300 for these deliverables. Payment will be made in the following installments:

Installment 1: $1,100, upon receipt of Task 1 deliverables (report describing systems).

Installment 2: $2200, which includes $1,100 for Task 2 deliverables (statistics to parameterize TOA-MD model), and $1,100, for Task 3 and 4 deliverables (report on data, analysis and results).

Contractor is responsible for adequately motivating the appropriate host-country investigators to provide the above-specified deliverables. This motivation may include, in some cases, financial compensation. Arrangements for any such compensation should be made with the knowledge and approval of the Lead USPI, Lead HCPI, and other relevant AquaFish investigators in your project and country.

ANNEX 4: MATERIAL PROVIDED FOR TASKS 1 AND 2 FOR CAMBODIA PSC

Summary statistics: Cambodia-farmers with mixed fish species but no snakehead fish culture adaptation

Variable	Province				
	Phnom Penh	Kandal	Preveng	K.Cham	K.Chhnang
Total cage size (m^3 =L*W*D)	1507.31	1021.44	403.50	986.08	3074.90
Average cage size (m^3)	99.67	71.42	27.75	50.58	106.39
	(55.70)	(88.35)	(29.61)	(53.05)	(85.90)
Average non- fish culture income (USD/Year)	1377.61	1767.00	1435.00	3602.50	3167.27
	(2580.87)	(1855.89)	(1923.69)	(8760.07)	(2051.71)
Average Household size (persons)	5.88	6.16	6.11	5.38	5.24
	(1.72)	(1.66)	(2.31)	(1.60)	(1.79)
Average fish yield (kg/m^3)	55.20	44.43	49.88	46.42	44.66
	(21.91)	(14.52)	(23.97)	(22.18)	(16.90)
Average price of fish (USD/kg)	1.36	1.84	1.59	1.14	1.38
	(0.26)	(1.22)	(0.58)	(0.52)	(0.18)
Production cost of fish (USD/m^3)	32.33	52.10	23.09	22.88	32.72

Note:
1. Mixed fish species in cage culture system
2. No snakehead culture adaptation

Number of households
non-fish income, define
cage units m3 vs ha
farm size

Summary Statistics: Cambodia-farmers with snakehead fish culture, low adaptation

Variable	Province				
	Phnom Penh	Kandal	Preveng	K.Cham	K.Chhnang
Total cage size (m^3 =L*W*D)	1103.95	806.00	467.62	474.92	1163.60
Average cage size (m^3)	92.00	26.00	13.36	22.62	55.41
	(59.00)	(16.10)	(7.99)	(17.56)	(36.82)
Average non- fish culture income (USD/year)	1377.61	1767.00	1435.00	3602.50	3167.27
	(2580.87)	(1855.89)	(1923.69)	(8760.07)	(2051.71)
Average Household size (persons)	6.09	6.52	6.37	5.10	5.71
	(2.21)	(1.90)	(2.24)	(1.64)	(3.72)
Average fish yield (kg/m^3)	55.20	44.43	49.88	46.42	44.66
	(21.91)	(14.52)	(23.97)	(22.18)	(16.90)
Average price of fish (USD/kg)	1.36	1.84	1.59	1.14	1.38
	(0.26)	(1.22)	(0.58)	(0.52)	(0.18)
Production cost of fish (USD/m^3)	32.33	52.10	23.09	22.88	32.72
Average Snakehead yield (kg/m^3)	98.96	197.16	129.25	91.02	103.36
	(50.36)	(78.16)	(49.99)	(55.29)	(49.26)
Average price of Snakehead (USD/kg)	1.34	1.37	1.10	1.30	1.57
	(0.27)	(0.17)	(0.24)	(0.17)	(0.30)
Production cost of Snakehead (USD/m^3)	30.63	50.12	32.10	19.41	31.02

Note:
1. Mixed fish species in cage culture system
2. Include snakehead culture (small scale and only one cage)

Summary Statistics: Cambodia-farmers with snakehead fish culture, high adaptation					
Variable	Province				
	Phnom Penh	Kandal	Preveng	K.Cham	K.Chhnang
Total cage size (m^3 =L*W*D)	1289.40	1305.55	1114.10	1038.70	1352.50
Average cage size (m^3)	107.45	43.52	55.71	69.25	64.40
	(61.65)	(34.41)	(27.94)	(60.17)	(38.68)
Average non- fish culture income (USD/year)	1377.61	1767.00	1435.00	3602.50	3167.27
	(2580.87)	(1855.89)	(1923.69)	(8760.07)	(2051.71)
Average Household size (persons)	5.68	6.35	6.03	5.29	5.10
	(2.25)	(1.98)	(2.41)	(1.79)	(2.10)
Average fish yield (kg/m^3)	55.20	44.43	49.88	46.42	44.66
	(21.91)	(14.52)	(23.97)	(22.18)	(16.90)
Average price of fish (USD/kg)	1.36	1.84	1.59	1.14	1.38
	(0.26)	(1.22)	(0.58)	(0.52)	(0.18)
Production cost of fish (USD/m^3)	32.33	52.10	23.09	22.88	32.72
With one cage only					
Average Snakehead yield (kg/m^3)	98.96	197.16	129.25	91.02	
	(50.36)	(78.16)	(49.99)	(55.29)	
Average price of Snakehead (USD/kg)	1.34	1.37	1.10	1.30	
	(0.27)	(0.17)	(0.24)	(0.17)	
Production cost of Snakehead (USD/m^3)	30.63	50.12	32.10	19.41	
With large-scale and more than one cage					
Average Snakehead yield (kg/m^3)	99.30	194.97	131.25	95.31	98.59
	(42.81)	(77.61)	(48.85)	(52.92)	(43.04)
Average price of Snakehead (USD/kg)	1.35	1.39	1.14	1.32	1.52
	(0.24)	(0.16)	(0.17)	(0.14)	(0.25)
Production cost of Snakehead (USD/m^3)	30.52	51.84	21.59	23.30	31.16
Note:					
1. Mixed fish species in cage culture system					
2. Include Snakehead culture (large-scale and more than one cage)					

ANNEX 4: MATERIAL PROVIDED FOR TASKS 1 AND 2 FOR VIETNAM PSC

APPLICATION OF PELLETED FEED FOR SNAKEHEAD FISH CULTURE IN THE MEKONG DELTA OF VIETNAM

Le Xuan Sinh[2], Huynh Van Hien, Nguyen Hoang Huy & Nguyen Thi Minh Thuy

Fish culture in ponds and cages is very common in freshwater areas of the Mekong Delta of Vietnam (MKD), where aquaculture plays a very important role in national fisheries production. Snakehead fish with two popular species are most preferred by the community in the MKD. The farming of giant snakehead *(Channa micropeltes)* was commenced in the 1960s while the farming of common snakehead fish *(Channa striatus)* was begun in 1990s and spread widely in the flood-prone areas of the Mekong Delta.

Snakehead fish are cultured in semi-intensive or intensive systems in different farming systems such as earthen ponds, cages, garden ditches. Long et al. (2004) estimated the production of cultured snakehead in the MKD in 2002 to be about 5,300 tones, mainly from An Giang, Dong Thap, Can Tho and Kien Giang provinces. The most recent production of cultured snakeheads in the delta estimated by Sinh et al (2010) was approximately 30,000 tones and 40,000 tones in 2009 and 2010, respectively. Giant snakeheads contributed about 25% of the total production. Most of the snakehead fish farmers surveyed in this study practiced aquaculture spontaneously at small scale without any planning or sector management. However, the information on snakeheads is not much available while there are many issues need to be solved for further development of these species in the delta, in particular, the dependence on the supply of seed and feed (trash fish or low value fish which provides an important source of food/protein for a significant proportion of the delta population).

The survey of 544 snakehead fish farms in MKD in 2009 was funded by Aquafish-CRSP show that the cultured area, volume and yield of fish varied significantly between five typical farming systems in operation. In order to harvest 1.0 kg of snakehead, about 4.0-4.5 kg of trash fish were used. All snakehead farmers used freshwater trash fish during flood season, but about 56.7% of total amount of trash fish for snakehead fish culture was from marine capture. The major difficulties faced by fish farmers included: (1) lack of capital (2) pollution of the culture area and difficulty in treating fish diseases (3) unstable price of table fish, and (4) increasing price of trash fish. These difficulties have resulted in decreasing profits and increasing numbers of unsuccessful farmers. If the cost of self-captured trash fish was not taken into account, the success rate of fish farmers was about 60-80% per crop, but it was only 40-50% if the cost of own-captured trash fish was included. Using trash fish for snakehead fish culture has taken away low value food fish from a significant proportion of the local community, and created a higher pressure on not only freshwater fish stock but also marine aquatic resources. Management of the snakehead farming sector should be given more careful consideration, especially in terms of seed and credit supply, replacements or alternatives to trash fish, water pollution management, and marketing of snakehead products.

The use of pelleted or commercial feed has been commenced by several snakehead fish farmers in the delta since 5-6 years ago, mainly for experiments. The surveys of CRSP project in the MKD (Phase 1) which were conducted in 2008-2009 showed that there were 9 farmers among 549 common snakehead farmers applied pelleted feed (or 1.64%) only. In order to have a better understanding on the development of snakehead farming and the application of pelleted fish, an additional survey was conducted from May to July of 2011. This survey was focused on the farming of common snakeheads in earthen ponds, and helped to describe two types of farming practices of common snakeheads in the MKD (System 1 and System 2), in particular to provide the data tables for Minimum Data Modeling. The data were collected

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from a total of 83 snakehead farmers, consisting of 39 non-users of pelleted but only trash fish (System 1), and 44 farmers applied pellet feed (System 2). These farmers located in 2 main producers of common snakeheads, An Giang and Dong Thap provinces.

The main results are summarized as follows:

- ♠ Both cultured area and pond size of the non-user group (System 1 - the fish farmers who did not use pelleted feed) were smaller than those of the user group about 10-20%. However, 65.4% of non-user farmers had 2 ponds and more while the figure for System 2 was 45.4%.
- ♠ Non-users (System 1) had bigger household size with 6.6 persons, of which 2.6 labors who participating in farming snakeheads while these respective number of user group (System 2) were 4.0 and 1.9 persons.
- ♠ More proportion of user group practicing 2 crops per year than those of non-user group (97.7% compared to 92.3%) while the remaining cultured fish with smaller number of crops per year. But the crop duration was about 8 days shorter for user group (171 days in comparison to 179 days).
- ♠ Fish seed/fingerlings in System 1 (non-user group) were respectively stocked at a larger size (1.1 cm and 0.6 cm in diameter), and a higher density in terms of both area and volume (for example, 41.8 and 33.7 fingerlings per cubic meter, respectively).
- ♠ The size of fish at harvest was almost the same between groups of non-users and users of pelleted feed (0.73 kg and 0.72 kg/fish) but the survival rates was significant different (63.7% and 75.3%) and seemed to be strange in comparison to the expectation of higher survival rate for non-user group (trash fish only). This might be caused by the quality of feed and the ways of feeding.
- ♠ There is an increasing rate of farmers using pelleted feed. If 132 pond fish farmers in 2008-2009 (Phase 1) using pelleted feed (6.82%), and assumed that the number of pond farmers is unchanged the rate of using pelleted feed was estimated about 33.33% in 2011.
- ♠ All feed in System 1 was trash fish while 92.4% of total amount of feed used in System 2 was commercial feed, approximately. The remaining was trash fish which was used at the beginning stage of stocking time for training fingerlings and other feed.
- ♠ FCR (Food Conversion Ratio) of System 2 (1.4) was much lower than that of System 1 (4.1), showing that pellet feed helped to reduce the amount of feed used, and might be also the residuals o feed and level of water pollution. The FCR for applicants of pellet feed was almost the same level of FCR for other fish/shrimp species (1.4-1.8).
- ♠ Using pellet feed required less feed costs for each kg of fish harvested with 29,900 VND/kg for user group (in System 2) compared to 32,100 VND/kg of non-user group) in System 1.
- ♠ The unit production cost per kg of fish produced by non-user group was 36,600 VND/kg, higher than that of System 2 (34,700 VND/kg). The share of feed in the total costs seemed to be the same between two systems (86.9% and 88.4%).
- ♠ The average yield of fish by cultured area was 444.7 tones/ha/crop while that of System 2 was 285.3 tones/ha/crop. It might be more different if the yield by cubic meter of cultured volume was used, for example 16.1 and 9.8 kg/m^3/crop, respectively.
- ♠ The selling price of fish in System 1 was also higher (42,800 VND/kg compared to 39,600 VND/kg). This might be caused by the different in the time of harvest. However, the differences in both production costs and selling prices did not make any difference in Benefit: Cost ratio, all were 1.3.

- ♠ Each non-user household spent a total cost of 1,641.9 mil.VND for all economic activities per year, of which 92.2% was paid for snakehead farming activities. These numbers for the user group were 1,376.4 mil.VND and 89.6%, respectively.
- ♠ Total net income per year from all economic activities of each non-user household was higher (633.81 mil.VND and the contribution of snakeheads was 80.4%). For the pelletted feed users, these figures were 384.98 mil.VND and 62.5%. It means that if the households had diversified sources of income or less dependent on snakeheads then they might be easier to apply pelleted feed.
- ♠ Two reported reasons for the non-user group who did not use pelleted feed are: (i) trash fish is easier to be digested, and (ii) using trash fish have better survival rate.
- ♠ Four recorded reasons for application of pelleted feed consist of: (i) faster growth of fish, (ii) cost reduction, (iv) lack of trash fish, and (iii) better management of feed.
- ♠ In the coming time, for non-user group: 17.9% would reduce the use of trash fish while 61.1% would be not willing to apply pelleted feed. For current user group: 50% would increase the use of pelleted feed. It is also interesting when 7.1% of non-user group and 25% of user group preferred to use both types of feed (combination of trash fish and pelleted feed).

Table 1: Major information from snakehead farming systems

Variable	**Non-users of pelleted feed** (n_3=39)	**Users of pelleted feed** (n_6=44)	**Grand Total** (all of farms) (n=83)
General information			
Average farm size in area (m^2)	1245.5	1332.0	1291.4
±	614.5	1139.6	926.2
Average farm size in volume (m^3)	3633.1	4070.1	3864.8
±	2046.3	3084.1	2641.3
Number of ponds (% of farms)	100.0	100.0	100.0
1 pond (%)	43.6	54.6	49.40
2 ponds (%)	25.6	22.7	24.1
≥ 3 ponds (%)	30.8	22.7	26.5
Average area of pond or pond size (m^2)	805.8	926.7	869.9
±	544.9	1158.3	919.2
Average volume of pond (m^3)	2380.6	2714.1	2557.4
±	1808.1	2706.7	2320.5
Average household size (persons)	6.6	4.0	5.9
±	5.3	3.2	4.9
Average number of family labors (labor) participating tin snakehead culture	2.6	1.9	2.3
±	1.2	1.1	1.2
Technical information			
Number of crop per year (%)	100.0	100.0	100.0
1 crop (%)	2.6	2.3	2.4
1.5 crops (%)	5.1		2.4
2 crops (%)	92.3	97.7	95.2
Average stocking duration per crop (days)	179.4	171.0	174.1
±	2.9	9.6	8.8
Average stocking density by area (ind./m^2)	115.7	91.1	102.7
±	102.9	92.4	97.7
Average stocking density by volume (ind./m^3)	41.8	33.7	37.5
±	39.0	42.4	40.8
Average size of seed (diameter in cm)	1.1	0.6	0.8
±	0.6	0.1	0.4
Average weight of fish at the harvest (g/fish)	728.2	718.2	722.9
±	195.6	214.9	204.9
Average survival rate (%)	63.7	75.3	69.8
±	24.1	16.0	20.9
Ave. feed conversion ratio-FCR	4.1	1.4	2.7
±	1.3	0.4	1.6
Percentage of pelleted feed used (%)	0.0	92.4	49.0
Ave. fish yield per crop (tons/ha/crop)	444.7	285.3	360.2
±	301.0	315.3	317.0
Ave. fish yield per crop by volume (kg/m^3/crop)	16.1	9.8	12.8
±	12.1	10.0	11.4
Economic information			
Ave. variable cost per crop (‘000 VND/m^3)	532.6	326.2	423.2

Variable	Non-users of pelleted feed (n_3=39)	Users of pelleted feed (n_6=44)	Grand Total (all of farms) (n=83)
±	363.8	372.7	380.7
Ave. total cost per crop (‘000 VND/m^3)	534.6	327.1	424.6
±	365.4	373.0	381.7
Ave. total gross income per crop (‘000 VND/m^3)	706.3	399.6	543.7
±	562.7	399.1	504.0
Ave. total net income per crop (‘000 VND/m^3)	173.7	73.0	120.4
±	313.2	113.1	233.9
Ave. variable cost per crop (mil. VND/ha)	14605.3	10138.0	12237.1
±	9329.9	12543.6	11308.4
Ave. total cost per crop (mil. VND/ha)	14659.1	10165.6	12277.0
±	9369.2	12554.0	11332.1
Ave. total income per crop (mil. VND/ha)	19392.6	15329.3	17238.6
±	14121.7	28633.9	22946.1
Ave. total net income per crop (mil. VND/ha)	4787.2	5179.0	4994.9
±	8223.6	22345.3	17123.4
Ave. unit total cost (‘000 VND/kg)	36.6	34.7	35.6
±	13.3	8.9	11.2
Ave. feed cost (‘000 VND/kg fish)	31.3	30.2	30.7
±	10.5	9.3	9.8
+ Share of feed costs to total cost for fish (%)	86.9	88.4	87.7
±	10.9	5.8	8.5
Ave. selling price of fish (‘000 VND/kg)	42.8	39.6	41.1
±	5.8	5.2	5.7
Ave. B:C ratio (Gross income/Total cost or Selling price/Unit total cost) (time)	1.3	1.3	1.3
±	0.4	0.7	0.6
Total production costs of household for all economic activities (‘000 VND/year)	1641921.1	1376435.6	1501181.8
±	855711.3	2502005.3	1907826.3
+ Of which, % of costs for snakeheads (%)	92.2	89.6	90.8
±	12.5	13.5	13.0
Total Income of household from all economic activities (‘000 VND/year)	2270762.1	1759938.0	1999963.8
±	1387345.0	2628996.5	2140589.9
+ Of which, % of income from snakeheads (%)	87.6	81.8	84.5
±	14.3	17.3	16.1
Total Profit or net income of household from all economic activities (‘000 VND/year)	633808.2	384981.0	501899.8
±	748056.8	534438.5	651698.6
+ Of which, % of profit from snakeheads (%)	80.4	62.5	70.3
±	24.1	30.9	29.3

Figure 1: Location of the Mekong River Delta

ANNEX 4: MATERIAL PROVIDED FOR TASKS 1 AND 2 FOR CHINA PSC

The following report was provided to satisfy Task 1 of the PSC. In addition, Excel files for the TOA-MD model were provided to the IA team (available from the IA team on request). As noted in the report, however, the data in these files were found to be logically inconsistent and based on an erroneous survey design and implementation, and therefore were unusable.

Impact Assessment of system using best management practices for integrated waste management:

Hubei Province Case study

1 Design

1.1 Population

The population represented is fish farms in Hubei Province, China.

1.2 Best Management Practices (BMP) system

BMP system is based on the concept where existing resources (in the form of organic wastes and by-products) on and around the fish farm are utilized as nutrient inputs to the pond and also to other agricultural activities. Organic wastes and by-products are not used exclusively for the pond, but from the ponds (in the form of pond mud and nutrient-rich water) to other farm activities such as vegetable production. On the other hand, the fish stocking density and time for oxygen aerator usage are controlled in the best way to manage the water quality, in order to improve the fish growth rate as well as the fish yield.

1.3 Systems

System 1: small fish pond scale (10-20 mu, 1 mu=667 m^2),

high fish stocking density,

no use of oxygen aerator,

fish species including common carp *Cyprinus carpio*, crucian carp *Carassius carassius*, grass carp *Ctenopharyngodon idella*, silver carp *Hypophthalmichthys molitrix*, bighead carp *Arigtichthys nobilis*, black carp *Mylopharyngodon piceus* and Chinese Wuchang bream *Megalobrama amblycephala*;

crops including rice, cotton, cole, soybean and some kinds of vegetables;

livestock including pig and chicken.

System 2: using BMP system, large fish pond scale (50-100 mu),

proper fish stocking density,

use of oxygen aerator,

fish species including common carp *Cyprinus carpio*, crucian carp *Carassius carassius*, grass carp *Ctenopharyngodon idella*, silver carp *Hypophthalmichthys molitrix*, bighead carp *Arigtichthys nobilis*, black carp *Mylopharyngodon piceus* and Chinese Wuchang bream *Megalobrama amblycephala*;

crops including some kinds of vegetables and grass as fish feed;

chicken as the main livestock.

1.4 Indicators

Mean farm income and per-capita income

Poverty rate

2 Data

The data required for the analysis can be divided in two types:

2.1 Farm data

Farm Size (mu)

Fish pond size (mu)

Household size (persons)

Herd size (head)

2.2 Economic data

For each activity (fish, rice, cotton, cole, soybean, vegetables, pig and chicken)

Yield (kg/mu)

Standard deviation of yield

Price of output ($/kg)

Variable cost ($/mu)

Fixed cost ($/mu)

Gross return (RMB/ mu)

Net return (RMB/ mu)

Impact Assessment of system using integrated culture model: Hainan Province Case study

1 Design

1.1 Population

The population represented is shrimp farms in Hainan Province, China.

1.2 Integrated Culture Model (ICM) system

ICM system is based on the concept that culture shrimp, other kinds of fish species and seaweeds together. The manure of shrimp and fish can be used as the fertilizer for seaweeds growth. Seaweeds absorb the inorganic nutrient from pond water, and release dissolved oxygen to the pond water, improve water quality and maintain it stable.

1.3 Systems

System 1: intensive shrimp culture (shrimp monoculture)

fish pond scale 10-20 mu, each pond about 3-5 mu, use of oxygen aerator, one 1.0 kw aerator/mu pond,

high shrimp stocking density, 8-10 × 10^4 individual/mu

feeding commercial assorted feed only

System 2: using ICM system

fish pond scale 10-20 mu, each pond about 5-10 mu,

use of oxygen aerator, one 1.0 kw aerator/two mu pond,

shrimp culture with other fish species, such as yellow grouper *Epinephelus awoata*, mullet *Mugil cephalus*, tilapia, mud crab *Scylla paramamosain*

Organic water wastes used to culture seaweeds *Gracilaria verrucosa*

shrimp stocking density, 3-4 × 10^4 individual/mu

feeding commercial assorted feed and freeze mixed small fish

1.4 Indicators

Mean farm income and per-capita income

Poverty rate

2 Data

The data required for the analysis can be divided in two types:

2.1 Farm data

Farm Size (mu)

Fish pond size (mu)

Household size (persons)

2.2 Economic data

For each activity (shrimp, fish, seaweeds)

Yield (kg/ha)

Standard deviation of yield

Price of output ($/kg)

Variable cost ($/mu)

Fixed cost ($/mu)

Gross return (RMB/ mu)

Net return (RMB/ mu)

ANNEX 5: PAPER PREPARED FOR PRESENTATION AT THE SHANGHAI 9AFAF CONFERENCE

This paper is available for download, along with the PPT from the conference presentation, at tradeoffs.oregonstate.edu.

ANNEX 6: REPORT PREPARED BY GRADUATE STUDENT XIAOJUAN JHENG

Description of the DREAM Model and Data Issues for Application to AquaFish CRSP Investigations

Xiaojuan Zheng

Apart from the basic static model for research evaluation, evaluations of the economic effects of research involve procedures to account for the timing of streams of benefits and costs, since there may be lengthy lag times between the initial investment in research, the eventual adoption of research results, and the flow of research benefits. A complete evaluation of a particular research investment must therefore take account of the dynamic relationships between investments in research that lead (after some lags) to a stream of future benefits.

The **DREAM** approach is based upon the economic surplus method. **DREAM** is developed assuming the following conditions:

- multiple regions, *i*
- producing a homogeneous product
- with linear supply and demand in each region
- with exponential (parallel) exogenous growth of linear supply and demand
- with a parallel research-induced supply shift in one region (or multiple regions)
- with a consequent parallel research-induced supply shift in other regions
- with a range of market-distorting policies
- with zero transport costs (at least initially)
- with a research lag followed by a linear adoption curve up to a maximum
- with an eventual linear decline

Besides considering only the benefit side of the cost-benefit equation, additional work would be needed, measuring the present value of the costs of achieving the supply shift, to complete the analysis. The model, summarized briefly below, is the conceptual basis for the *DREAM* computer program that has been developed for research priority setting and evaluation

5. General Form of Supply and Demand

For region *i* in year *t*, linear supply-and-demand equations for a particular commodity (subscript suppressed) are specified as

Supply: $Q_{i,t} = \alpha_{i,t} + \beta_i PP_{i,t}$
Demand: $C_{i,t} = \gamma_{i,t} + \delta_i PC_{i,t}$

The first subscript, *i*, refers to a region, and the second subscript, *t*, refers to years from the initial starting point of the evaluation. The slopes are assumed to be constant for each region for all time periods. The intercepts may grow over time to reflect underlying growth in supply or demand due to factors other than research (i.e., growth in productivity or income). All of the variables are expressed in real terms so that any growth is real growth. One important implication of this is that the discount rate used in subsequent analysis to compare costs and benefits of research over time must be a real rate.

6. Initial Parameterization

The parameters of the supply-and-demand equations are defined by beginning with initial (t=0) values of

- quantity consumed in each region – $C_{i,0}$
- quantity produced in each region – $Q_{i,0}$
- producer price in each region – $PP_{i,0}$
- consumer price in each region – $PC_{i,0}$
- elasticity of supply in each region – $\varepsilon_{i,0}$
- elasticity of demand in each region – ${}_{i,0}$ (<0)

In many cases, the initial values of elasticities would be assumed to be equal among regions (a convenient, but not necessary, assumption).

7. Exogenous Growth in Supply and Demand

Average exponential growth rates are incorporated to reflect growth in demand (due to growth in population and income) and supply (due to growth in productivity or an increase in area cropped) that is expected to occur regardless of whether the research program of interest is undertaken.

Research-Induced Supply Shifts

Local effect of research: Let region i undertake a program of research with

- probability of success p_i, which, if the research is successful and the results are fully adopted, will yield
- a cost saving per unit of output equal to c_i percent of the initial price, $PP_{i,0}$ in region i, while
- a ceiling adoption rate of A_i^{MAX} percent holds in region i

Spillover effects of research: The *spillover effects* from region i to other regions, j, are parameterized in relation to the supply shifts in region i, implicitly assuming the same adoption curve applies in every region.

With-Research Supply and Demand

To model the with-research case (denoted by superscript R on all relevant variables and parameters), we take the intercepts from the without-research case (but include the effects of exogenous supply growth), add the effect of the supply shift to them.

The models for supply and demand that reflect the local and spillover effects of research are

$$Q^R_{i,t} = \alpha^R_{i,t} + \beta_i PP^R_{i,t},$$
$$C^R_{i,t} = \gamma^R_{i,t} + \delta_i PC^R_{i,t}.$$

8. Market-Clearing Rules

For all of the scenarios to be considered, there is an overall quantity clearing rule to the effect that the sum of quantities supplied equals the sum of quantities demanded in each year.

Free trade: The easiest case is that of free trade, where without-research and the with-research market-clearing prices under free trade can be given.

Generalized taxes and subsidies: We can define a general solution for a large variety of tax or subsidy regimes by setting out a general model in which a *per unit* tax is collected from consumers in every region and from producers in every region.

A subsidy is a negative tax, so it is also possible to use these to represent subsidies on output, consumption, imports, or exports.

The small-country case: The small-country case can be represented in this model without modification. However, to do that requires getting information—that is not useful otherwise—on quantities produced and consumed in the rest of the world. The alternative is to define the market-clearing price for equations as an exogenous parameter.

Other policies: Conceptually, the approach is to define target price and allow it to determine output in regions where it applies. Then, with that supply as exogenous, supply equations in the other regions and demand equations in all regions would interact to determine price.

Welfare Effects: A set of equations for welfare effects given should be correct for most (if not all) types of policies (i.e., market-clearing rules).

9. Aggregation over Time and Interest Groups

The model so far is capable of generating an indefinitely long time series of prices, quantities, and economic surplus measures for the regions of interest for a range of tax or subsidy policies. The remaining problem is to aggregate those measures into summary measures of research benefits.

6. *Economic data needed to implement an analysis for following two cases:*

Case1. "Development of alternatives to the use of freshwater low value fish for aquaculture in the Lower Mekong River basin of Cambodia and Vietnam"

Case2. "China: impact of imposing environmental regulations on carp/tilapia and shrimp farms"

- Relative price of low value fish
- Price of other aquaculture feeds
- Production and consumption of LVF
- Price elasticities of supply and consumption for alternative feeds
- Price elasticities of supply and consumption for carp/tilapia
- Production and consumption growth rate
- oxygen aerator consumption
- Consumption of food fish, especially on the value added products and value chain of snakeheads
- Consumption of commercial feed
- Pellets and Small-sized fish stock and Utilization rate for snakeheads agriculture
- Production costs of both captured wild fish and cultured fish
- Cost saving per unit of fish
- Income of farmers
- Quantity of water supply, and effluent water
- Policies used and probability of success
- Adoption rate for snakehead aquaculture
- R&D time lag
- Real discount rate
- Market level of supply and demand
- Province-level data on production in some period time
- Demand for fish in Hainan & Hubei province

7. Data Limitations and Issues:

AquaFish CRSP assessment faces the additional challenge that the structure for collecting project-specific assessment data, and resources to support such collection, have not been built into the CRSP investigation workplans and must be added after the investigations have been partially completed. Opportunities for collecting some relevant baseline (pre-project) data thus are lost, and resources for gathering other data are unavailable.

- The variety of AquaFish CRSP's ongoing investigations, the current absence of essential data and any mechanisms that would generate it, and the requirement of addressing all four Global Themes and all four Core Program Components, places a high burden on any assessment methodology.

- We have not obtained any useful data source from related researchers working in China.

- It is hard to get access to obtain useful data from online, eg, China data center in University of Michigan(http://chinadatacenter.org/) and Economic research service (ERS http://www.ers.usda.gov/).

Project Planning Meeting on AquaFish Technology Discovery and Impact Assessment

Technology Adoption and Policy Development/Study/09TAP06OR

Steve Buccola and John Antle
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Corvallis, Oregon, USA

ABSTRACT

Effective planning of future CRSP projects requires that we understand how well past projects have achieved their objectives and what factors have contributed to that success or failure. In the present meeting, AquaFish researchers came together to examine methods of assessing the extent of both a research discovery itself and its impact on an economy, ecosystem, and community. The participants applied these methods to begin assessing research discoveries in the 2007 – 2009 and 2009 – 2011 AquaFish cycles, and impacts of these discoveries in a sub-set of those investigations.

INTRODUCTION

This Investigation consisted of a Project Meeting, held October 4 – 7, 2010 in Seattle, Washington, of AquaFish host-country investigators who had agreed to take a host-country leadership role in the AquaFish Project, "Assessing the Impacts of CRSP Research: Human Capital, Research Discovery, and Technology Adoption." Participants reviewed methods of research discovery and impact assessment, began applying the methods to 2007 – 2009 and 2009 – 2011 AquaFish investigations, and made plans for the continuance of that work through the project termination on December 2011.

OBJECTIVES

The objectives of the Meeting were to:

(a) Set up the legal and administrative framework for the individuals' participation in the Project.

(b) Review the procedures for research discovery and impact assessment.

(c) Begin applying those procedures to AquaFish investigations.

(d) Make plans for completing the assessments by the end of the 2009 – 2011 AquaFish cycle.

The Meeting was designed to tie in with our Project Workshop that had been held on 1 March 2010 in San Diego, and with our Workshop planned for (and subsequently held on) 18 April 2011 in Shanghai.

PARTICIPANTS

Meeting leaders were John Antle (then at Montana State University) and Steve Buccola (Oregon State University). Lin Qin (research assistant, Department of Agricultural and Resource Economics, Oregon State University) assisted with the research discovery topics. Roberto Valdivia (research associate, Department of Agricultural and Resource Economics, Montana State University) assisted with the with impact assessment topics. Valdivia also handled flight and visa arrangements with participants, and local-planning and administration in Seattle.

Each of the seven U.S. university-based AquaFish projects was represented by two host-country investigators. Host-country participants were, alphabetically listed by U.S. university name:

University of Arizona

Wilfrido Contreras, Universidad Juarez Autonoma de Tabasco, Mexico
Pablo Gonzalez, Universidad Juarez Autonoma de Tabasco, Mexico

North Carolina State University

Evelyn Ayson, Southeast Asian Development Center, Philippines
Remedios Bolivar, Central Luzon State University, Philippines

University of Michigan

Zexia Gao, Huazhong Agricultural University, China
Vu Cam Luong, Nong Lam University, Vietnam

University of Hawaii

Eladio Gaxiola, Universidad Autonoma de Sinaloa-Culiacan, Mexico
Erick Sandoval, Universidad Centroamericano, Nicaragua

Auburn University

Gertrude Atukunda, National Fisheries Resources Research Institute, Uganda
Khalid Salie, Stellenbosch University, South Africa

University of Connecticut

So Nam, Inland Fisheries Research and Development Institute, Cambodia
Le Xuan Sinh, Can Tho University, Vietnam

Purdue University

Steve Amisah, Kwame Nkrumah University of Science & Technology, Ghana
Sebastian Chenyambuga, Sokoine University, Tanzania

Other AquaFish guests attending:

Hillary Egna (AquaFish Director)[3]
Kwamena Quagrainie (US PI of the Purdue University Project)
Emanuel Frimpong (Virginia Tech University and collaborator on the Purdue University Project)
Laura Morrison and Lisa Reifke of the Oregon State University AquaFish Synthesis Project staff.

[3] ***ME Editors Note***: *Dr. Egna did not attend this meeting.*

PROCEDURES

Preparatory material was sent to the participants several weeks ahead of the Project Meeting, introducing participants to the objectives and agenda and summarizing the more technical aspects of what would be conducted in Seattle.

Day *One* of the Meeting was devoted to presentations by the Meeting staff (Antle, Buccola, Valdivia, and Qin) and by seven of the seven of the host-country attendees. The staff presentations focused on: (a) the principles of research discovery assessment, emphasizing Bayesian statistical methods and careful specification of each experimental or survey treatment; and (b) the principles of impact assessment, emphasizing the expected profitability of the new technology in specified settings and the importance in profitability assessment of accurately depicting the decision maker's economic situation. The host-country presentations consisted of summaries of their ongoing AquaFish investigations.

On Days *Two* and *Three* of the Meeting, Antle and Valdivia conducted research impact assessments with subsets of the attendees, developing preliminary characterizations of a decision maker's economic environment and applying minimum-data (TOA-MD) software to estimate the probabilities of new-technology adoption in that environment. Simultaneously, Buccola and Qin met successively in break-out sessions with each project-level pair of investigators to conduct research discovery assessments and discuss plans for future work. Laura Morrison and Lisa Reifke participated in these break-out meetings.

On Day *Four* of the Meeting, plans were drawn up with individual AquaFish projects to continue this work into FY 2011. Much of this discussion regarded the structures of the Personal Services contracts to be signed with seven of the 14 host-country attendees and under which many of the aspects of this Project will be conducted. In the ensuing several weeks, PSC contracts were signed with Steven Amisah, Gertrude Atakunda, Remedios Bolivar, Wilfrido Contreras, Zexia Gao, Eladio Gaxiola, and So Nam.

SCHEDULE

Sunday, 3 October

All day	*Arrivals*

Monday, 4 October

8:00 – 8:30	Welcome & Introductions
8:30 – 9:00	RD – Intro to Research Discovery part of project meeting
9:00 – 9:30	IA – Intro to Impact Assessment part of project meeting
9:30 – 10:00	*Break*
10:00 – 12:00	Project representatives summarize and discuss their work
12:00 – 1:00	*Lunch*
1:00 – 2.45	RD – Methods for assessing research discoveries
2:45 – 3:15	*Break*
3:15 – 5:00	IA – Methods for assessing research impacts

Tuesday, 5 October

8:00 – 9:45	IA – Methods (continued). Data preparation and data spreadsheet
9:45 – 10:15	*Break*
10:15 – 12:00	RD -- Break-out sessions with project teams
	IA -- Data preparation exercise
12:00 – 1:00	*Lunch*
1:00 – 2:45	RD – Examples and problems in research output and input measurement
	IA – Discussion of Data Template and data issues
2:45 – 3:15	*Break*
3:15 – 5:00	RD -- Break-out sessions with individual projects
	IA – Project teams identify technologies and data for their investigations
6:30	Meet in hotel lobby, depart to reception in Space Needle

Wednesday, 6 October

8:00 – 9:45	IA – Minimum Data software
9:45 – 10:15	*Break*
10:15 – 12:00	RD -- Break-out sessions with individual projects
	IA – MD software exercises
12:00 – 1:00	*Lunch*
1:00 – 2:45	RD – Examples and problems in research output and input measurement
	IA – Review and discussion of MD software exercises
2:45 – 3:15	*Break*
3:15 – 5:00	RD -- Break-out sessions with individual projects
	IA – Project teams finalize plans for their investigations

Thursday, 7 October

8:00 – 10:00	Summary of progress
	Project teams report on IA plans
10:00 – 10:30	*Break*
10:30 – 12:00	Planning our next steps for assessing AquaFish discoveries and impacts
12:00 – 1:00	*Lunch*
1:00 – 5:00	Other AquaFish business (Laura Morrison)

Break-Out Sessions

	Time	Group (by name of USPI)	Meet with
Morning 10:15-12:00			
	10:15-11:20	Borski	Steve Buccola
	10:15-11:20	Diana	Lin Qin
	11:20-11:55	Haws	Steve Buccola & Roberto Valdivia
	11:20-11:55	Pomeroy	Lin Qin
Afternoon 03:15-05:00	03:15-04:20	Molnar	Steve Buccola
	03:15-04:20	Quagrainie	Lin Qin
	04:20-04:55	Fitzsimmons	Steve Buccola
	04:20-04:55	Pomeroy	Lin Qin

CONCLUSIONS

Besides its immediate and principal role of advancing the objectives of the *Impacts of CRSP Research* Project, this Meeting provided host-country participants with instruction and hands-on experience in research discovery and impact assessment methods. Those skills are essential for developing an understanding of the effectiveness of CRSP projects and thus for the future of CRSP research. Furthermore, although the skills imparted at this Meeting were expressed in terms of aquacultural research and outreach, they are easily applicable to other technical settings and situations as well and thus their communities' and countries' more general development interests.

Effects of ACRSP and AquaFish CRSP Initiatives and Activities on Aquaculture Development in Kenya

Technology Adoption and Policy Development/Study/09TAP07PU

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Purdue University
West Lafayette, Indiana, USA

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Kenyatta University
Nairobi, Kenya

ABSTRACT

This study sought to determine the technical efficiency of fish farms adopting ACRSP and AquaFish CRSP knowledge and technologies and also identify factors affecting technical efficiency of fish farming in Kenya. The study used primary data that was collected from 118 fish farmers in Kenya. A stochastic production frontier model of technical efficiency was applied to the data obtained from the fish farmers. Findings suggest that farmer's operated at inefficient levels which could be improved through better management of production inputs. The mean technical efficiency for fish farmers in Kenya is 69%, indicating that production can be enhanced in the short-run by increasing technical efficiency by 31% under current production technologies. The results also suggest that farms operating with smaller ponds and farmers aware of ACRSP and AquaFish CRSP activities and have participated in them operate at more efficient levels.

INTRODUCTION

Agriculture is the most important economic activity in the Kenyan economy, accounting for more than 25% GDP and 80% of employment (GOK, 2011). The sector is typically driven by small producers who usually cultivate no more than two hectares of land (about five acres) using limited technology. These small farms, operated by about 3 million farming families, account for 75% of total agricultural production. With rapidly increasing population growth and lack of land to expand agricultural production, farmers are faced with the challenge of meeting their food and income needs from those limited resources. This has led farmers to diversify agriculture through production of high value crops including export cash crops and most recently aquaculture production.

Aquaculture in Kenya was a little known and young industry in spite of fish culture practices that had existed for decades. Kenya's aquaculture consists mainly of small-scale commercial tilapia (*Oreochromis niloticus*), and also catfish (*Clarias gariepinus*), producing only about 1,000 metric tons annually until the early 2000. In 2007, however, the government reported annual production from aquaculture of about 4,220 metric tons of fish valued at Kshs 500 million. The Government of Kenya has recognized aquaculture as a sub-sector with great potential to contribute towards poverty alleviation in rural communities, dietary protein enhancement, and reducing pressure on capture fisheries. To harness and exploit this sector that could potentially create wealth, employment and improve food security, the Kenya government adopted a strategy to expedite aquaculture growth, through a collaborative and participatory approach, involving both public and private sectors through Public-Private partnerships (FAO, 2007). The government also introduced the fish farming enterprise productivity program under the economic stimulus program for promoting aquaculture growth. In 2009/10 the government spent Kshs 1.12 billion to implement the project and also Kshs 2.866 billion for the 2010/11 financial year.

On the Public-partnership collaborative projects, USAID's started the Aquaculture Collaborative Research Support Program (ACRSP) in 1990. ACRSP work activities involved improving technical knowledge and efficiency at the farm level so as to increase fish production in a more cost-effective way (ACRSP, 2011). In 2000, ACRSP adopted an intervention strategy of addressing the constraints of availability of quality juvenile fish for stocking private ponds since the use of poor quality juveniles usually resulted in poor survival at the early stages of fish propagation. ACRSP also focused on addressing the availability of farm records for use in farm business planning since lack of adequate records on fish farming prevented lending institutions from taking serious interest in investing in aquaculture. ACRSP embarked on a series of training programs that taught record keeping and various hatchery techniques and nursery management that could be adopted by farmers for producing fish for the food market as well as for producing baitfish for the commercial fisheries. ACRSP has provided appropriate technical support and intervention strategies in the form of extension services and aggressive research (ACRSP, 2011). ACRSP later became Aquaculture and Fisheries CRSP (AquaFish CRSP) and embarked on a series of training programs that taught record keeping and various hatchery techniques and nursery management that could be adopted by farmers for producing fish for the food market as well as for producing baitfish for the commercial fisheries.

Improving fish farming technology is important to the economic growth and development of rural communities. Improved technologies are necessary to help fish producers respond to changing circumstances and raise productivity and household incomes. Technical change with the adoption of new technologies in fish farming is particularly important in Africa to enable sustainable economic growth and increased production with minimal resources.

Since the inception of ACRSP and AquaFish CRSP activities, no study has been carried out to assess the impact of CRSP activities at the micro (farm and household) and at the macro (government and policy). This study sought to assess the impact levels of ACRSP and AquaFish CRSP activities in Kenya. The specific objectives of the study were:

10. Assess the technical efficiency of fish farms adopting ACRSP and AquaFish CRSP knowledge and technologies

11. Assess the determinants of adoption of ACRSP and AquaFish CRSP technologies

12. Assess the extent to which ACRSP and AquaFish CRSP initiatives and activities meet the objectives of contributing towards poverty alleviation in rural communities, protein enhancement, and reducing pressure on capture fisheries.

DATA

Data for this study was collected in the months of June and July, 2011 in Kenya. A sample of 297 farmers were randomly selected in 10 counties (Busia-60; Kakamega-62; Kiambu-21; Kiriinyaga-22; Kisumu-1; Muranga-20; Nyandarua-1; Nyeri-28; Ol Kalou -1; Siaya-33; Trans Nzoia-18; Vihiga-30;). However, only 118 responses were used for the production and efficiency model because they contained completed responses that were relevant to the model. To make a comparative analysis of the ACRSP and non-ACRSP trained farmers, a dummy was created for respondents who have participated in ACRSP activities and included in the model. This method was used as an alternative to analyzing the two sets of farmers separately due to the size of the sample, which was relatively small for such an analysis.

ANALYTICAL MODEL

Adoption of ACRSP knowledge and technologies may be influenced by a number of factors such as local economic, social and environmental factors, as well as spatial characteristics. For example, Quagrainie et al (2009) reported that farmers in the Western province have a 19% more probability of using credit facilities for their fish farming operations than farmers from the Rift Valley, Central and the Eastern provinces. Market proximity, transport infrastructure, land and labor availability, and other local ecological characteristics could also help explain adoption practices and consequently, productivity (Nelson 2002, Mertens et al 2002).

Techniques for the measurement of technical efficiency of production can be broadly categorized into two approaches: parametric and nonparametric. The most popular among empirical analysts are the parametric stochastic frontier production function (SFP) approach (Aigner, Lovell and Schimidt, 1977) and the nonparametric mathematical programming approach, also called the data envelopment analysis (DEA) (Charnes, Cooper and Rhodes, 1978; Färe et al., 1989; Färe, Grosskopf and Lovell, 1994). The main strengths of the SFP approach are that it deals with stochastic noise and permits statistical tests of hypotheses pertaining to production structure and degree of inefficiency. However, the methodology requires imposing an explicit parametric form for the underlying technology and distributional assumption for the inefficiency term (Coelli, 1995; Sharma, Leung and Zalleski, 1999). The main advantages of the DEA approach are that it avoids parametric specification of technology and any distributional assumption for the inefficiency term. However, DEA is deterministic and attributes all the deviations from the frontier to inefficiencies, consequently a frontier estimated by DEA is likely to be sensitive to measurement errors and other noise in the data (Coelli, 1995).

This study used the SFP function as proposed by Aigner, Lovell & Schimidt, (1977) and Meeusen & van den Broeck (1977). The SFP function specification permits output to be specified as a function of controllable factors of production, random noise and a technical inefficiency term. The SFP function, thus, has two error terms; one to account for random effects (e.g., measurement errors in the output variable, weather conditions, diseases, etc. and the combined effects of unobserved/uncontrollable inputs on production) and another to account for technical inefficiency in production. The SFP function can be written as

(i) $$Y_i = X_i\beta + (v_i - \mu_i), i = 1\ldots,N;$$

where Y_i is the production of the i^{th} farm, x_i is a vector of inputs used by the i^{th} farm; μ_i is a vector of unknown parameters, v_i is a random variable which is assumed to be independently and identically distributed (iid) N(0, σ_v^2) and independent of the μ_i; and μ_i is a random variable that is assumed to account for technical inefficiency in production and following Battese & Coelli (1995) it is assumed to be independently distributed as truncation (at zero) of the normal distribution with mean, μ_i and variance, $\sigma_u^2(|N(\mu_i, \sigma_u^2)|)^3$ where,

(ii) $$\mu_i = Z_i\delta$$

where Z_i is a 1 x c vector of farm-specific variables that may cause inefficiency and δ is c x 1 vector of parameters to be estimated.

The farm-specific SFP representing the maximum possible output (Y*) can be expressed as:

(iii) $$Y_i^* = f(X_i;\beta)\exp(V_i)$$

Substitution iii) into i) yields,

(iv) $$Y_i = Y_i^* \exp(-U_i)$$

Thus, technical efficiency of the i^{th} farm, denoted by TE_i , is given by:

(v) $$TE_i = \frac{Y_i}{Y_i^*} = \exp(-U_i)$$

The difference between Y and Y^* is the inefficiency term U_i where Y is equal to Y^* when $U_i = 0$, and the production lies on the stochastic frontier. This implies that the farm is technically efficient and obtains its maximum possible output given the level of inputs. If $U_i > 0$, production lies below the frontier and the farm is technically inefficient. The maximum-likelihood estimates (MLE) of the parameters of the model defined by (i) and (ii) and the farm-specific TE defined by (*v*) are obtained mostly using FRONTIER Version 4.1 (Coelli, 1994).

Empirical model

For a preliminary analysis, a Cobb-Douglas (CD) functional form was used to measure the physical relationship between inputs and output.

(vi) $$\ln Y = A_0 + \sum_{n=1}^{n} \beta_n \ln x_n \ldots.where\ldots A_0 = \ln \beta_0$$

ln represents the natural logarithm; Y is observed farm output (kg/ha); x_1 is stocking density (No. of fish/ha); x_2 is the feeding rate (kg/ha); x_3 pre-harvest labor use (family and hired person-days/ha). Other functional forms that can be adopted include the transcendental logarithmic (translog) frontier functional form.

RESULTS AND DISCUSSION

Statistical Summaries

Statistical descriptions of selected social economic characteristics of the farmers surveyed indicated that most farmers are aged between 30 to 60 years with the mean range between 40 and 50 years. Most farmers are educated up to the secondary level. The range of farm income is from Kshs 5,000 to 10, 000 while the non-farm income is mostly below Kshs 5,000. The average farm size is 3.8 acres and the average number of people living in each household is about 8 persons.

A description of variables used in the stochastic and technical efficiency model is presented in Table 1. The average output of fish per hectare is 8,654 kg, which has a high standard deviation implying that there is a wide disparity in the production output of fish in Kenya. The output revenue also shows similar trends. The output revenue per hectare is Kshs 2.93 million with a standard deviation of Kshs 23.2 million. Input variables show smaller standard deviations in comparison to output and revenues. The average number of seed (fingerlings) per hectare is 27,892 with a standard deviation of 11, 886. The average feed weight applied per ha is about 76 kg with a standard deviation of 74.66 and the total man days per hectare is about 46.49 with a standard deviation of 44.57.

Maximum likelihood estimates

The results of the maximum likelihood estimates for the stochastic frontier model and the farm-specific inefficiency model are presented in Table 2. Results show that the variance parameter (γ) 0.18 is highly significant suggesting that technical inefficiency effects are significant in explaining the levels and variations in fish production in Kenya and that inefficiency effects are not stochastic.

Frontier Model

The maximum likelihood estimates of the parameters were estimated under the assumption of half normal distribution for the dataset. The results in table 2 show no significance effects of inputs use in fish production though the signs on feed and labor showed the expected positive sign. The absence of statistical significance on the estimated coefficients of the input variables is unexpected. Given that this preliminary analysis utilized a Cobb-Douglas functional form, other functional forms suggested in the literature such as the transcendental logarithmic (translog) frontier functional form will be fitted to the model to compare results. The translog frontier function will also allow combinations of square and cross effects to improve the fit of the model.

Technical inefficiency model estimates

The coefficient estimates show that farming experience, awareness and participation in ACRSP activities, number of training, pond size, marital status, size of the household and presence of children below age 15 years are determinants of inefficiency. The negative signs of the coefficient estimates for awareness and participation in ACRSP activities, marital status and presence of children below the age 15 indicate an inverse relationship to technical inefficiency. This implies that farmers who are aware of and have participated in ACRSP activities operate at higher technical efficiency than their counterparts who are unaware of ACRSP activities and have not participated in ACRSP programs. ACRSP activities over the years have covered several relevant topics including site selection, pond construction, construction of fish hatchery systems, fish propagation techniques, fingerling transportation, fish feed preparation, record keeping, etc. Emphasis has been placed on the growth of the whole chain of activities from farm to the consumer; better management of the natural resources; and increased profitability of fish production at the farm level. Therefore, it is not surprising that farmers with knowledge of and participated in ACRSP activities are efficient producers of fish in Kenya. Farmers who are married and having children under the age of 15 years are also found to be more efficient than those who are single or widowed and without children below the age of 15 years respectively.

The results in table 2 also show positive relationships of farming experience, number of training attended, pond size and size of household to technical inefficiency. This implies that those variables are positively correlated with technical inefficiency. The positive effects of farming experience and number of trainings appear to be counter intuitive. Though the age variable is not statistically significant but positive, Coelli and Battese (1996) have suggested that experienced farmers who tend to be older farmers are more conservative and are among the slow adopters of new technologies. The result could also imply that new fish farmers avoid mistakes by experienced fish farmers and adopt new technologies faster resulting in a more efficient production. The coefficient of pond size is positive and statistically significantly suggesting that pond size affects production efficiency. In this case, fish farms with smaller ponds are less inefficient (or more efficient) than farms with large ponds. Smaller ponds tend to be more manageable in terms of labor needs, stocking, feeding, harvesting, etc., than larger ponds.

The estimated technical efficiency of the respondents, as defined by equation (v), ranges from 49% to 100%, with a mean of 69%. This implies that, on the average, fish farmers in Kenya are producing fish at about 69% of the potential frontier production levels, given the present state of technology and input levels. Alternatively, the 69% efficiency level also implies that 31% of the technical potential in farmed fish output is not realized and steps should be taken to achieve the additional 31%. With the Kenyan government economic stimulus program in aquaculture, the aquaculture industry should be able to close this gap in potential fish output from fish farming.

The estimated technical efficiencies for fish farms in Kenya range from less than 5% to 100% (figure 1). Of the 118 farms examined, about 24% (28 farms) have technical efficiency index of less than 0.50; 7% representing 8 farms have indices from 0.50 to 0.59; 8% (10 farms) operate between 0.60 and 0.69 efficiency levels; 19% (22 farms) operate at 0.70-0.79 efficiency levels; 15% (18 farms) from 0.80-0.89; whilst 27% (32 farms) have a technical efficiency index of 0.90 or above. It suggests that 61% of the fish farms operate at technical efficiency levels of 70% and above. This presents a challenge to the Kenya government and developmental agencies for enhanced technology transfer programs to improve farm level adoption of fish production enhancing technologies.

CONTRIBUTIONS OF ACRSP AND AQUAFISH CRSP INITIATIVES AND ACTIVITIES

One of the primary objectives of the study was to assess the extent to which ACRSP and AquaFish CRSP programs have contributed to poverty alleviation in rural communities, protein enhancement, and reducing pressure on capture fisheries. This was undertaken by comparing the differences in household incomes and home consumption of fish between two groups of households: fish farmers who have participated in any fish farming program sponsored by ACRSP and AquaFish CRSP (44 farmers) and those who have not (73 farmers). It is assumed that aquaculture production can be very profitable if managed properly based on the knowledge gained from the various training programs, leading to higher incomes for farming households. Increases in income, in turn, may translate into higher expenditures for protein-rich foods such as fish. In addition, households may take their fish consumption needs into account in their fish production patterns and consume some of their own production.

Fish farmers who had participated in ACRSP and AquaFish CRSP programs had a mean household income of Ksh178,632 per year while fish farmers who had not participated in any programs had a mean farm income of Ksh156,492. The difference in farm income of Ksh22,140 was not statistically significant. The amount of fish that was consumed at home by the household also differed between the two groups of fish farmers. While the mean amount of fish consumption was 32kg per year for households who had not participated in any CRSP programs, the mean amount consumed by CRSP program participants was 256kg. The difference of 224kg was also not statistically significant between the two groups. Given these results, it appears that from the short-run perspective, adoption of aquaculture production technologies do not have immediate result in substantially reducing household poverty though an increase in farm incomes is realized with households that had participated in CRSP development programs. The level of total production by fish farmers who have been trained by CRSP is comparatively higher and increasing steadily. In the short run, adoption of ACRSP and AquaFish CRSP production technologies can only start to improve the economic and nutritional situation of rural households as well as supplementing fish supply from capture fisheries at the margin; the initial step in a much broader effort to improve the welfare of rural communities in Kenya. The Kenyan government’s enterprise productivity program under the economic stimulus program is very much a medium to long-run objective to harness and exploit the aquaculture sector to potentially create wealth, employment and improve food security.

CONCLUSION

This study sought to determine the technical efficiency of fish farms adopting ACRSP and AquaFish CRSP knowledge and technologies and also identify factors affecting technical efficiency of fish farming in Kenya. Preliminary findings show that farmer’s technical efficiency can be improved through better management of inputs of production. Based on the findings presented, adoption of aquaculture technologies has not improved household incomes, bettered dietary quality or reduced pressure on capture fisheries in the short run. The government initiatives to increase fish production under the economic stimulus program are steps in the right direction for achieving these noble objectives in the long run. The collaborative and participatory approach for developing aquaculture involving the Kenya government and public and private agencies through public-private partnerships should be continued. This approach is supported by results from this study indicating that farmers aware of ACRSP and AquaFish CRSP activities and have participated in their programs operate at more efficient levels.

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Table 1: Description of variables used in the stochastic and technical efficiency model

Variables	Description	Mean	Std. Dev.	Min	Max
Output (Y)	Total farm fish production (kg/ha)	8,654	57,808	20	625,000
Input					
Seed	Total number of fingerlings stocked (no./ha)	27,892	11886	5000	111,000
Feed	Total dry weight of feed applied in ponds kg/ha)	75.94	74.66	3.3	666.66
Labor	Family and hired labor used in fish production (man-days/ha)	46.79	44.57	4.9	238.33
Farm Specific Factors					
Experience	Number of years the farmer has been engaged in fish farming	4.96	8.17	1	50
ACRSP awareness / training	Value =1 if respondent is aware and trained under ACRSP, 0 otherwise	0.37	0.49	0	1
Trainings	Total number of trainings the farmer has received	3.81	4.10	0	20
Pond size	Total size of ponds (in m^2)	857	772	175	4,890
Age	1 if above 50 years, 0 otherwise	0.25	0.44	0	1
Marital Status	1 if married, 0 otherwise	0.87	0.33	0	1
Education level	1 if educated up to secondary school, 0 otherwise	0.80	0.40	0	1
Household income	1 if greater than Kshs 30, 000 , 0 otherwise	0.30	0.46	0	1
Household size	Total number of people living in the household	7.72	3.53	1	18
Children below 15	1 if children below 15 years present, 0 otherwise.	0.84	0.37	0	1

Table 2: The maximum likelihood estimates of the Cobb-Douglas stochastic frontier model and those in the inefficiency model are represented below

lnY	Coefficient	Std. Error	t	P>|t|
Production frontier				
Seed	-0.133	0.133	-1.005	0.317
Feed	0.037	0.172	0.214	0.831
Labor	0.063	0.138	0.459	0.647
Constant	8.731	1.248	6.994	0.000
Technical inefficiency model				
Experience	0.070**	0.028	2.509	0.014
ACRSP awareness/training	-3.783***	0.776	-4.873	0.000
Trainings	0.077**	0.037	2.057	0.042
Pond size	0.000***	0.000	-3.108	0.002
Age	0.835	0.592	1.412	0.161
Marital Status	-1.730**	0.693	-2.495	0.014
Education level	0.257	0.306	0.838	0.404
Household income	0.986	0.693	1.423	0.157
Household size	0.179***	0.052	3.448	0.001
Children below 15	-0.480**	0.201	-2.396	0.018
Variance parameters				
sigma-squared (σ^2)	1.68***	0.289	5.804	0.000
gamma (γ)	0.18***	0.065	2.746	0.007
Number of observations	118			
Log likelihood	-187.28			
Mean of exp(-U)	0.688			

*, **, *** indicate significance levels 0.1, 0.05 and 0.001 respectively

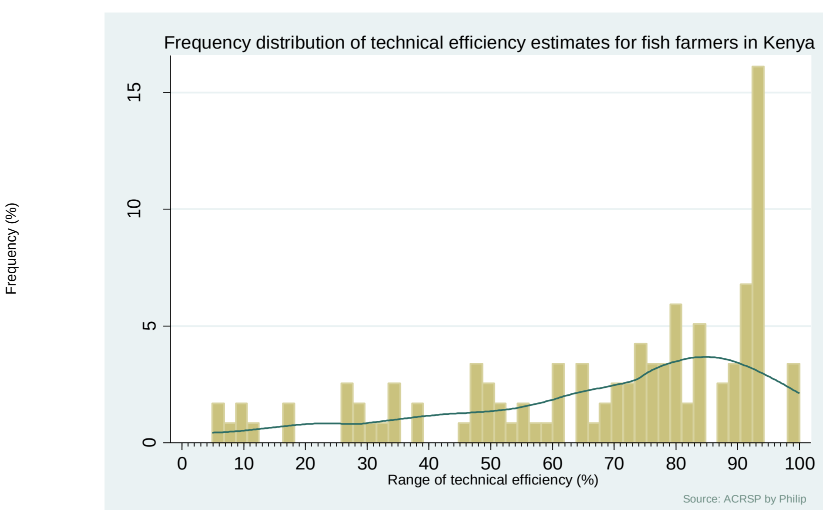

Figure 1: Frequency Distribution of Technical Efficiency Estimates

Training Trainers for Long Term and Sustained Impact of Pond Aquaculture in Africa

Technology Adoption and Policy Development/Activity/09TAP08AU

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[This report has not yet been submitted]

Market Assessment and Profitability Analysis of Aquaculture Enterprises in Uganda

Marketing, Economic Risk Assessment & Trade/Study/09MER01AU

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ABSTRACT

By focusing on aquaculture technology for smallholder farmers, this project conducted market assessments and profitability analysis of smallholder aquaculture enterprises in Uganda. Aquaculture farm-level production costs, management practices, and marketing arrangements were assessed by documenting the number, size, and location of existing aquaculture producers and processors and the current markets they serve. The risk-return tradeoffs associated with a given aquaculture enterprise were quantified in isolation and in conjunction with alternative enterprises using enterprise budgets and portfolio analysis frameworks. Fish marketing and credit issues in the country were identified using secondary data and literature reviews. Information on marketing and credit flows was gathered using a combination of face-to-face interviews/survey questionnaires and purposeful selection of respondents. This report presents a summary of the activities accomplished that relate to profitability analysis of aquaculture enterprises, fish marketing, credit for fish marketing and production, and economic modeling for fisheries marketing development.

INTRODUCTION

Growing evidence and experience indicate that sustaining success in productivity-based agricultural growth critically depends on expansion of market opportunities (Diao and Hezel, 2004; Gabre-Madhin and Haggblade, 2004) and requires thinking beyond productivity to incorporate profitability and competitiveness (Kaplinsky, 2000). It is now increasingly evident that smallholder farmers' key concern is not only agricultural productivity and household food consumption, but also increasingly better market access. Virtually all African farmers depend on trading for some household needs, and hence seek income generating activities. Enhancing the ability of smallholder, resource-poor farmers to access market opportunities, and diversify their links with markets is one of the most pressing development challenges facing both governments and nongovernmental organizations in Sub-Saharan Africa (IFAD, 2001; IFPRI, 2002; Kindness and Gordon, 2002). Agricultural markets can therefore play significant roles in reducing poverty in poor economies, especially in countries which have not already achieved significant agricultural growth.

In Sub-Saharan Africa, more countries are increasingly putting emphasis on transforming subsistence agriculture to make farming a business and to an entrepreneur culture in rural communities, where farmers produce for markets rather than trying to market what they produce, to better understand how communities in diverse situations can best achieve their income and other livelihood aspirations through better links with markets. What is not obvious, however, is how to make small-scale farming more market orientated, and how to make markets work for the poor. Experience has shown that markets can fail the poor, especially poorest and marginalized groups, including women.

By focusing on aquaculture technology for smallholder farmers, this project conducted market assessments and profitability analysis of smallholder aquaculture enterprises in Uganda. Until recently, most fish farmers were poor people in villages who practiced aquaculture for subsistence with ponds of usually less than 500 m² constructed using family labor (Jagger and Pender, 2001; Nyombi and Bolwig, 2004). These were low or no input production systems, with little or no need for routine management. However, with rising market prices for fish, the quest for profitable production, and stagnating supply from capture fisheries, farmers are beginning to build more and larger ponds of 1,000 m², and using higher stocking densities (Department of Fisheries Resources 2005). Before deciding whether to undertake, continue or to expand a commercial aquaculture enterprise, aquaculturist needs to evaluate potential profitability. This report presents a summary of the activities accomplished that relate to profitability analysis of aquaculture enterprises, fish marketing, credit for fish marketing and production, and economic modeling for fisheries marketing development.

METHODS AND MATERIALS

Aquaculture farm-level production costs, management practices, and marketing arrangements were assessed by documenting the number, size, and location of existing aquaculture producers and processors and the current markets they serve. The risk-return tradeoffs associated with a given aquaculture enterprise were quantified in isolation and in conjunction with alternative enterprises using enterprise budgets and portfolio analysis frameworks. Fish marketing and credit issues in the country were identified using secondary data and literature reviews. Information on marketing and credit flows was gathered using a combination of face-to-face interviews/survey questionnaires and purposeful selection of respondents.

RESULTS

Main Results from the Farmers' Survey

Only 36 percent (n=72) of the farmers interviewed had fish farming as their main source of income. The other 64 percent (n=128) farms had a wide range of other livelihood activities. Although some of the farmers interviewed had been involved with fish farming for many generations, there appeared to be an increasing number of people who were starting to practice aquaculture.

Although many farmers regarded it as source of income, it is not regarded as important as other sources of income, rather one that could be used sporadically. More farms cultured tilapia and catfish compared with any other fish species. When asked to indicate the species grown for their last harvest, the majority (82 percent) reported tilapia. The majority (61 percent) of the farms solicited additional labor (1 to 5 people) during harvest and most of this additional help was paid labor.

The majority of farms fed their fish with maize bran (47 percent) followed by Ugachic feed (24 percent), but a proportion also used crop leaves and pellets. Nearly all of the farmers interviewed cultured fish in ponds rather than cages. A high number of farmers (64 percent) owned between 1 or 2 ponds

Farmers obtained their fry/fingerlings from a variety of different sources with the most common source of fish seed being from Kajjansi fisheries institute (58 percent) followed by Mpigi and Umoja fish farm. The stocking density of fingerlings ranged from 100 fish to 9,050 fish with most farmers stocking at between 351-550 fish. Only 45 percent of the farms surveyed made a profit from the last completed harvest. Over 90 percent of the farms surveyed used personal funds to finance their production.

The majority of the farms (76 percent) are not associated with any organization. Only 48 percent of the farms kept some form of written records related to their fish farming activities, relating mainly to production costs. Only 10% of farmers claimed to contact the extension officers with most farmers relying on their own experience or advice from other farmers.

Main Results from the Traders' Survey

The majority of the respondents (41%) were from Kampala district followed by Wakiso (23%), Mukono (20%) and Mpingi (16%) districts. Over half of the respondents (52%) were retail operators, and over 80 percent were business owners who use personal funds (not loans) to finance their fish businesses. About 77% of the respondents have been in the fish business for more than 5 years and most sold their fish at Busega (30%), Mukono (20%) and Mpigi (16%) markets.

Less than 1% of the traders sold farmed fish and when asked why they did not sell farmed fish, the most frequent response was lack of supply/scarcity. Tilapia is the most traded species and most of the respondents (60%) indicated buying fresh tilapia on a daily basis. Quality and freshness rather than price were considered to be most important factor considered when buying fish.

The majority of the traders (82%) lived closer (within 7 miles) to the markets where they sale fish. Refrigeration and smoking were the most common methods used to preserve unsold fish.
July was reported by 57 percent of the respondents as the month when fish is in low supply and May, June and August as the period when fish is in high supply. Fish price (22%), fewer customers (10%), corrupt fish officers (8%) and immature fish (8%) were the main problems identified by the traders as impediments to the sector. The majority (73%) of the traders did not belong to a traders' association.

Main Results from Enterprise Budgets and Profitability Analysis

All model farms made profit with net revenue ranging from Ushs 1,347,463 (US$ 596.60) to Ushs 2,643,818 (US$ 1,164.68). The enterprise budgets also indicated that it is profitable to farm one variety of fish rather than mixing. Farming catfish turned out to be more profitable than farming tilapia alone or mixing tilapia and catfish. The results also showed that keeping records as well as managing the pond using recommended practices results in higher returns.

DISCUSSION

Small-scale fish farmers located relatively close to markets or all-season roads, and who can supply consistent and high quality produce, have the widest range of marketing opportunities, and will likely be within the area of operation of potential traders and intermediaries that deliver fish to markets. Fish farmers that are not close to roads, or produce unreliable quantities and variable quality products are facing high transaction costs of marketing their product, and decreasing net returns to production. We also find that access to input markets are important factors leading to positive net returns to fish production.

The data show a need for improved market access and to develop new semi-processed and value-added products. There is a need for improved handling of the fish at the point of capture to diminish post-harvest losses. There are considerable losses through spoilage owing to lack of proper infrastructure exhibited by poor roads and landing sites. Another factor is the inadequate funding for effective fisheries regulations enforcement.

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Value Chain Development for Tilapia and Catfish Products: Opportunities for Women Participation

Marketing, Economic Risk Assessment, and Trade/Study/09MER02PU

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ABSTRACT

This investigation consisted of two parts: 1) consumer preference study and 2) value chain analysis. Analyses of the preferences of consumers in urban Kenya for farmed tilapia and catfish suggest that consumers have issues with farmed tilapia and catfish relating to availability and healthiness. Consumption is significantly dependent on the gender, marital status, age, family size, residential status and education of consumers; price of catfish and tilapia; and importance of the color, taste, smell and nutritional value to consumers. Regarding the value chain, the major actors included input suppliers, fish farmers, fish farmers/input suppliers and fish marketers. Input suppliers supplied farm inputs, greenhouse construction equipment suppliers and harvest equipment suppliers. Fish farmers are mainly grow-out farmers and fish farmers/input suppliers sold fingerlings and fry and thereby acted as hatcheries in addition to producing fish for the food market. Fish marketers included wholesalers, traders/processors. The preliminary findings suggest that high initial costs of fish farming in terms of land, training and construction needs to be addressed, despite government assistance through the ESP. This is one of the major constraints to increased female participation in the fish production stage. The SWOT analysis of all supply chain actors indicates a need for more information sharing. Nairobi fish marketers had the highest benefit-cost ratio suggesting that close proximity to urban markets could improve farm revenues.

INTRODUCTION

Aquaculture development in Kenya was identified as a core activity for funding in the New Partnership for Africa's Development (NEPAD) Action Plan in 2000. Since then Kenya's aquaculture production has risen from about 1,000 tons to almost 1,500 tons in 2006. Production in real terms has doubled and is set to grow by over 1,000% by 2010-2012. In 2003 total production of the three main fish species farmed in Kenya (Nile tilapia, rainbow trout and North African catfish) amounted to 948 tons. The value of production for 2003 came to US$ 2,153,000 (FAO, 2010).

The most important fish are tilapia and catfish. Tilapia species form about 90% of farmed fish in Kenya. Polyculture of tilapia with the African catfish (*Clarias gariepinus*) is often practiced. Semi-intensive systems form the bulk of aquaculture production in Kenya, contributing more than 70% of the total production from aquaculture. There are only a few intensive systems and hyper-intensive systems in Kenya. The latter are projected to contribute as much as 90% of all farmed fish in Kenya by both volume and value. Approximately 35% of tilapia produced in Kenya is produced in semi intensive systems, while 65% is produced in extensive systems. Approximately a third of Kenya's 5,900 fish farmers are commercial farmers although only four are large scale commercial enterprises. The remainder is rural, commercial small-scale fish farmers.

A review of past CRSP research studies in Africa suggests a strong production focus, leaving many fish consumer and marketing questions unanswered. The need to place some emphasis on consumer preference research and value chain development derives from the strategic challenges that the Kenyan aquaculture industry faces. A value chain is defined as the different stages of the fish production process, e.g. input supply, production, marketing, consumption, which are linked through different relationships.

There is limited distinction in the marketing of wild caught fish and farmed fish and the two often share the same marketing chain. Previous literature purports a very short marketing channel for aquaculture products in which producers link directly to consumers or retailers. Middlemen have a minimal or no role in the marketing channel. Farmed fish is usually produced at the village or farm level and individual farmers sell directly to individual consumers, fish retailers or nearby small establishments such as restaurants, schools, and hotels. Quantities sold are generally small and supply is inconsistent (Quagrainie et al., 2009). Schuurhuizen, et al., (2006) assert that the increase in international fish supply chains has led to disruptions in traditional arrangements and the traditional female roles are disappearing. Women participate at the peripheral parts of the value chain, such as fish processing and trading. However, as men enter the processing business they appear to displace women from those activities and women may also be required to work as laborers in male-managed agricultural activities. Wangila et al., (2007) reported that women operated almost exclusively as small-scale traders or fishmongers who bought and processed mostly small fish and sold locally. Traders usually had a specialty in which they traded; men traded mainly in medium and large fish while women traded mainly in small and medium fish. Women generally play a major role in the production, processing and marketing of agricultural products in many African countries. Their enhanced integration into the fish value chain could lead to improved economic wellbeing and help overcome inequalities and poverty for women thereby ensuring food security in Africa. Analyzing specific value-chain activities and integration of women would create some competitive advantage.

The purpose of this study was to understand consumer preferences and trends in the demand for tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) products in Kenya and to develop value chain involving women that could lead to economic growth and to help overcome underemployment and poverty among women. This study was structured around five main objectives:

1. **Identify the factors that influence consumer decision-making and purchase behavior regarding tilapia and catfish product options;**
2. **Examine consumers' preference structure and decision criteria for tilapia and catfish products that are farmed and wild caught;**
3. **Assess the state of women participation in fish value chain, identifying opportunities and constraints to improving their welfare;**
4. **Train women in fish value participation to identify points of intervention;**
5. **Develop a Farmed Fish Marketing Information System (FFMIS) based on consumer information and existing national fish farming inventory.**

OBJECTIVES 1 AND 2

Methodology

The data necessary to accomplish the objectives was collected from Nairobi, Kisumu, Nyeri, Eldoret and Nakuru in Kenya. The questionnaire solicited for information on the socio-demographic features, general fish consumption of consumers, information specific to the consumption of tilapia and catfish. The questionnaires were administered to randomly selected households; a total of 623 questionnaires were administered; 230 in Nairobi, 213 in Kisumu, 67 in Nakuru, 60 in Eldoret, and 53 in Nyeri. After excluding incomplete responses, the sample size reduced to 415.

Consumer preference for farmed tilapia and catfish was assessed on a likert scale of 0 to 3 (0 = not preferred; 1 = least preferred; 2 = preferred; 3 = most preferred). We analyzed the effects of the importance of sensory (taste, color and smell), functional (nutritional value) and symbolic (social status) attributes and the socio-demographic features of consumers (gender, marital status, income level, family size, household income and educational level) on the preferences of consumers for farmed tilapia and catfish. Taste, color, smell and nutritional value of farmed fish, and the social status of consumers were measured on a likert scale of 1 to 4; 1 being not important, and 4 being very important. Consumers were made to indicate how important these factors are to them when purchasing tilapia or catfish. A description of selected variables used to model preferences is reported in table 1. The prices of tilapia and catfish were estimated as the ratio of tilapia (catfish) expenditure to the quantity of tilapia (catfish) purchased per fish shopping. The data described was analyzed with an Ordered Logit model.

Since about 90% of farmed fish is tilapia, a second model for consumer preferences specific to farmed tilapia was estimated using a separate data set from a choice experiment that consisted of various levels of attributes. This included four levels of fish form (fresh, fried, dried and smoked), three levels of fish size (small, medium and large), and four levels of price - KSH 150, KSH 250, KSH 300 and KSH 400 for Kenya. The levels of size were described as 150-400g for small, 400-600g for medium and >600g for large, based on findings reported by Quagrainie et al. (2010). Having specified the attributes and their respective levels, the full factorial main effects experimental design was used to generate hypothetical tilapia profiles in SPSS 11. Because full factorial experimental design was used, all the possible treatment combinations were generated (Hensher, Rose and Greene, 2005). In all, 96 (2^1x3^1x4^2) hypothetical tilapia profiles were generated from which 48 questions were formed. Each question had three alternatives: A, B and C from which respondents were to make a choice. Alternatives A and B were two different hypothetical tilapia profiles, and alternative C was a “choose-neither-A-nor-B” (*status quo*) option. The random parameters logit was adopted to assess consumer choice for farmed tilapia.

Results

Majority of the consumers were females (about 54%); and their average age was 33years. The high proportion of females and high average age of the respondents are consistent with the culture in most parts of Africa where the principal shoppers of households are predominantly matured females. About 73% were married and the average household size was 3.8. Over 60% of the consumers live in urban areas while the rest live in semi-urban areas of the cities. All of the respondents had either primary (grade 1 to 6) or higher level of formal education, with majority of them (58%) being graduates of second cycle institutions and a few (3%) holding post graduate degrees. The average Kenyan household earned about $342 per month and spent $114 on food. On average, households in Kenya consume about 2.10kg (4.24lb) of fish per week. The most consumed fish species included tilapia, Nile perch, catfish, silver cyprinid, lungfish, haplochromis, kingfish and common carp in that other. Tilapia is the most frequently purchased fish by 78% of household in Kenya; and Nile perch and catfish are respectively among the three most frequently purchased fish by 48% and 40% of Kenyan households. Over 70% of Kenyan consumers purchase fish mainly from open markets. Supermarkets and landing sites are also important places for fish purchases. Supermarkets and landing sites are more important locations for fish purchases.

Ordered Logit model

The analyses utilized an ordered logit models for the tilapia and catfish response data (Table 2). For farmed tilapia, the residential status of consumers appears to have a positive and significant effect on the preference of consumers, revealing that consumers living in urban areas have a higher preference for farmed tilapia compared to those living in semi-urban areas. Also, the price of catfish has a positive and significant effect on farmed tilapia preference, suggesting that farmed tilapia and farmed catfish are substitutes, i.e., the higher the price of farmed catfish, the higher the preference of consumers for farmed tilapia. Regarding the sensory and functional attributes of farmed tilapia, the importance of the color, smell, nutritional value and social status have positive and significant effects (Table 2).

In the farmed catfish model female shoppers showed a negative and statistically significant effect indicating that female consumers have less preference for farmed catfish than male consumers. Age of consumers is positive and significant. Education showed significant effect on preferences. For example, tertiary and post graduate education had positive effects on preferences of consumers for farmed catfish suggesting that consumers with tertiary and post graduate education prefer farmed catfish compared to consumers with only primary education.

The effect of price of catfish is negative and significant as demand theory suggests; the higher the price of catfish, the lower the preference of consumers for farmed catfish. The taste, color, and smell of farmed catfish have positive and significant effects on the preference of consumers for farmed catfish indicating that the more important these factors are to consumers, the more likely they would purchase farmed catfish. The social status coefficient is positive and significant suggesting that the higher consumes view their social status, the more likely they would purchase farmed catfish.

The taste of farmed tilapia and catfish can be improved by feeding them with commercially formulated feed instead of household food wastes and just food generated in the pond. In some instances, pond algae eaten by fish impart unpleasant tastes to farmed fish. Although the use of commercially formulated feed can help improve the taste of tilapia, it may be unaffordable to small-scale farmers who are the majority of fish farmers in Kenya. However, the benefits to be realized by feeding formulated feed would outweigh the cost. The use of formulated fish feed should be encouraged.

Random Parameters Logit (RPL) model

In order to avoid dummy variable trap, one level of each attribute was omitted. The omitted attribute levels were “wild-caught”, “small size” and “dried form”. The attribute levels maintained in the model were effects coded relative to the omitted levels. Effects coding is used in order to avoid confounding the *opt-out* coefficient (Ouma, Abdulai and Drucker, 2007; Tonsor, Olynk and Wolf, 2009). All the non-price attributes of tilapia were assumed to be normally distributed in the population with the standard deviation. However, price was fixed in order to ensure a negative price coefficient over the entire sample. Fixing price also means that the willingness to pay (WTP) values will be normally distributed (Layton and Brown, 2000).

The RPL estimates are presented in table 3. The model has a McFadden-R^2 of 29.07% suggesting that the model has adequate fitness. The price coefficient is negative and strongly significant suggesting that consumers have a preference for lower tilapia prices, which is consistent with demand theory. The negative sign on the price coefficient corroborates with the result that over 70% of the consumers indicated that price is very important to them when buying tilapia on a scale of 1 to 4 (1=very important and 4=not important).

The “farmed” attribute has a negative and statistically significant coefficient suggesting a lower preference compared to wild caught tilapia. Although a proportion of the consumers (23%) indicated indifference between farmed and wild tilapia, most consumers generally do not ask about the mode of production (wild or farmed) of the tilapia they purchase. Consumers who do not prefer farmed fish gave health reasons and had the perception that cultured fish in general are produced with genetically modified feed or that chemicals like growth hormones, pesticides were used on farms.

The coefficient on “medium size” is negative but the coefficient on “large size” has a positive coefficient and is strongly significant, suggesting a preference for large size tilapia. The preferences of consumers for large size tilapia could be because large fish is relatively more fleshy and easy to fillet. Others consider big size as big enough for the entire household to share. Some consumers believe large fish are more attractive and tastier, healthier, and less bony compared to the medium and small ones.

Kenyan consumers have a strong preference for fresh tilapia. Kenyans are traditionally used to the consumption of fresh tilapia, and fresh fish in general, because of the frequent supply of fresh fish from especially Lake Victoria to open markets. Fresh tilapia sellers in Kenya usually offer to dress (remove scales and fins) their products for consumers at the points of sale in order to reduce the difficulty and time commitment involved in preparing fresh tilapia. These, among other things, are probably why Kenyan consumers strongly prefer fresh tilapia. “Fried” and “smoked” forms are statistically significant, but opposite in sign. This shows that consumers in Kenyan prefer fried tilapia but not smoked tilapia. Fried tilapia is highly preferred in Kenya probably because it is not only a delicacy, but it is also the main form of tilapia consumed with *ugali (made from maize)*, a local dish widely consumed throughout Kenya.

Table 3 also reports the standard deviations of the coefficients of the various farmed tilapia attributes. A statistically significant standard deviation of a coefficient indicates that the coefficient varies in the population, i.e. there is preference heterogeneity for that attribute. The results suggest that Kenyan consumers are heterogeneous in their preferences for farmed tilapia regarding the attributes of being farmed, medium size and fried.

OBJECTIVES 3 AND 4

Methodology

The primary focus of this study was female participation in the fish channel structure and economic and technical performance, which will be evaluated using value chain analysis (VCA) and cost-benefit analysis (CBA). The data and information used was collected from published literature, personal interviews with industry stakeholders and focus group discussions. Different questionnaires were used for the interviews of the different actors in the chain. The interviews determined industry stakeholders' perceptions of the current state and future outlook of increased female participation; and the focus group discussions provided a basis for the analysis for qualitative data (Humphrey, 2005).

The three survey areas visited were the Central region- Nairobi, Western region- Kisumu and the Rift Valley- Eldoret. Personal interviews were conducted for all respondents. Respondents included 6 input suppliers, 10 input supplier/fish farmers, 75 female fish farmers and 98 fish marketers.

The study used an integrated and interdisciplinary conceptual framework and scientific methodology in attempt to fully understand the intricate linkages between chain structure, performance and value added distribution and thereby determined optimal institutional arrangements of the different proposed models of female participation (Epstein, 1992; Taylor & Bogdan, 1998). VCA was used to map the different chains in terms of cost distribution (value addition), supply chain efficiency and income redistribution. The case studies and interviews with key aquaculture industry stakeholders determine the overall structure (technical and economic and performance of the various value chains. The study performed a CBA to assess financial efficiency and equity in order to determine profitability. However, due to data limitations, the CBA was only conducted on the fish farmers and fish marketers (wholesalers, retailers and traders). This assisted in identifying key economically viable opportunities for increased female participation in the catfish and tilapia value chains in Kenya. The field data that was gathered from

June to July 2011 form the basis for the results reported here. Much more detailed quantitative analysis is ongoing.

A workshop was conducted from 24th through 26th November 2010 in Mumias, Kenya. Participants at the workshop included 4 fish farmers who have been growing and marketing fish for over 5 years in Western Kenya and 15 fish traders from the Lake Victoria region. During their introduction, women traders narrated cases where their income has reduced over the years and that they were afraid there would be no fish to sell from Lake Victoria hence their need to find alternative livelihood. They mentioned aquaculture and expressed desire to begin farming fish as well as trading in farmed fish. All the four fish farmers talked of how successful they have been since they began to farm fish. They challenged women traders to venture into fish farming and that with time they would find farming fish has a better income that trading in capture fisheries.

Findings

The linkages between chain actors in the fish value chain structure in Kenya are examined. A flow chart of the relevant aspects of fish value chain is given in figure 1. The major actors included input suppliers, fish farmers, fish farmers/input suppliers and fish marketers. Input suppliers supplied farm inputs, greenhouse construction equipment suppliers and harvest equipment suppliers; fish farmers are mainly grow-out farmers; fish farmers/input suppliers sold fingerlings and fry and thereby acted as hatcheries in addition to producing fish for the food market; fish marketers, which included wholesalers, traders/processors. A SWOT analyses was conducted on all supply chain actors (Tables 4 - 6).

The key survey findings were

- Most fish farmers are small scale and/or only just starting and did not have previous harvest information or financial information and sell directly to consumers at the farm-gate. Most of the information gathered on fish marketing is based on wild caught fish but provided insights on farmed fish.
- Nairobi had the most diversity in terms of fish products- fresh, fried, dried, smoked, etc. Eldoret markets had mostly processed fish products.
- Markets in the Kisumu region had the most fish farmers and the best fish market in terms of facilities.
- The input suppliers for construction and harvest equipment were not exclusively aquaculture suppliers and only supplied these inputs because they were inputs that had other functions. This includes the recently established aquashops.
- Women form the majority of fish marketers and labor suppliers, and their numbers are increasing as farmers.
- The government Economic Stimulus Program (ESP) is the major program that has attributed to the increase in the number of ponds constructed
- There are 6 government accredited aquaculture equipment suppliers and 6 recently established aquashops.
- The main opportunities for women are as fish farmers which can also act as a hatchery and provide fingerlings and fry for additional income.
- Although access to larger markets is recommended in the long run, at their current small scale, sale to neighbors and the local community is advisable as it eliminates transport costs and the transaction costs of marketing.
- Additional women could also increase their welfare by entering the chain as fish marketers but this is not yet viable for farmed fish as they are not yet entering the formal markets

The main problems were

- Although the government ESP was a success, only 22 of the 75 fish farmers interviewed had as yet harvested.
- The microfinance providers were unwilling to be interviewed due to protocol, i.e. they are large corporations and permission was needed from head office. Others cited intellectual property rights for refusing to be interviewed.
- A few supply chain actors also expressed an unwillingness to provide financial data as they felt this was proprietary information. This makes it difficult to perform the benefit-cost and NPV analysis for these actors.

Participants at the workshop identified a wide range of constraints which limited the ability as women to engage in aquaculture value chain. These constraints were encountered in the different provinces and districts. The following were mentioned as constraints:

- Lack of training on business and management skills
- Lack of information on market demand, prices etc.
- Lack of saving and credit facilities including small and medium enterprise facilities
- Lack of a central marketing organization on the beach to bargain for better prices.

Cost-Benefit Analysis (CBA)

Ideally, CBA should be conducted for all the chain actors but many female were unwilling to share financial information, though some costs and revenues were calculated for some actors. A simple cost-benefit ratio that divides profit levels by the associated costs from each business type provides an indication of profitability. A cost-benefit ratio is therefore a profitability index. A ratio above one indicates that the business type is profitable while a ratio below one means that it is not. However, a detailed CBA would also include valuing benefits which are not directly expressed in monetary terms. For this report however, a simple cost-benefit ratio is calculated for selected fish farmers and fish marketers who shared information on actual costs and revenues. A more detailed CBA of all actors is ongoing.

Data used for the benefit-cost analysis for fish marketers excluded questionnaires completed by employees as they had insufficient knowledge of all the business costs and revenues. Data from commission sales agents was also excluded as these had no cost for fish stocks and could not verify their actual weekly turnover. The calculated cost-benefit ratios show that only 29 of the 86 respondents had a ratio higher than 1. Of these 29, 20 were females operators; 5 had been fish marketers 5 years or less (the average years of experience were 16 years); 2 had other income sources; and all 29 marketers obtained some of their fish from Lake Victoria. Only 5 obtained a small amount of fish from fish farms and 1 obtained fish exclusively from Lake Turkana.

Eighteen respondents with a benefit-cost ratio higher than 1 were from Nairobi (6 from City Market and 12 from Gikomba market), 7 from Kisumu and 4 from Eldoret. All 29 traded in tilapia, 21 also traded in Nile Perch and 14 traded in catfish. Eighteen performed only one business function (wholesale, retail, process) and 11 performed more than one function. Ongoing analysis will investigate whether location, gender, selection of single or multi- business functions, choice of fish to trade and choice of the source affect the ratios / profitability index. The exclusion of the commission based traders also raises the question of whether these excluded traders have a better benefit cost ratio. Further analysis will determine these issues.

Data used for the benefit-cost analysis for fish farmers came from 22 of the 75 fish farmers interviewed because they had harvested fish and kept records. Record keeping is still a challenge for many fish farmers. The overall benefit-cost ratio for the 22 dataset is 2.65 which is significantly higher than one and indicates that fish farming is indeed profitable. There were a few large operations included in the dataset and could have skewed the profitability index up. On individual basis, only 5 of the sample of 22 had benefit-cost ratios above 1. The others provided revenues for their first harvest so they still had large sunk costs, such as construction costs. It should be noted that although the cost-benefit ratio is based on factors value in monetary terms, a ratio below 1 but close to 1 do not necessarily suggest that the venture is not viable. There are other indirect societal benefits identified that would improve economic welfare. These include improved finances, improved food security, ready protein source, and enhanced community relations resulting from farm gate sales and employment opportunities for the community.

Conclusions

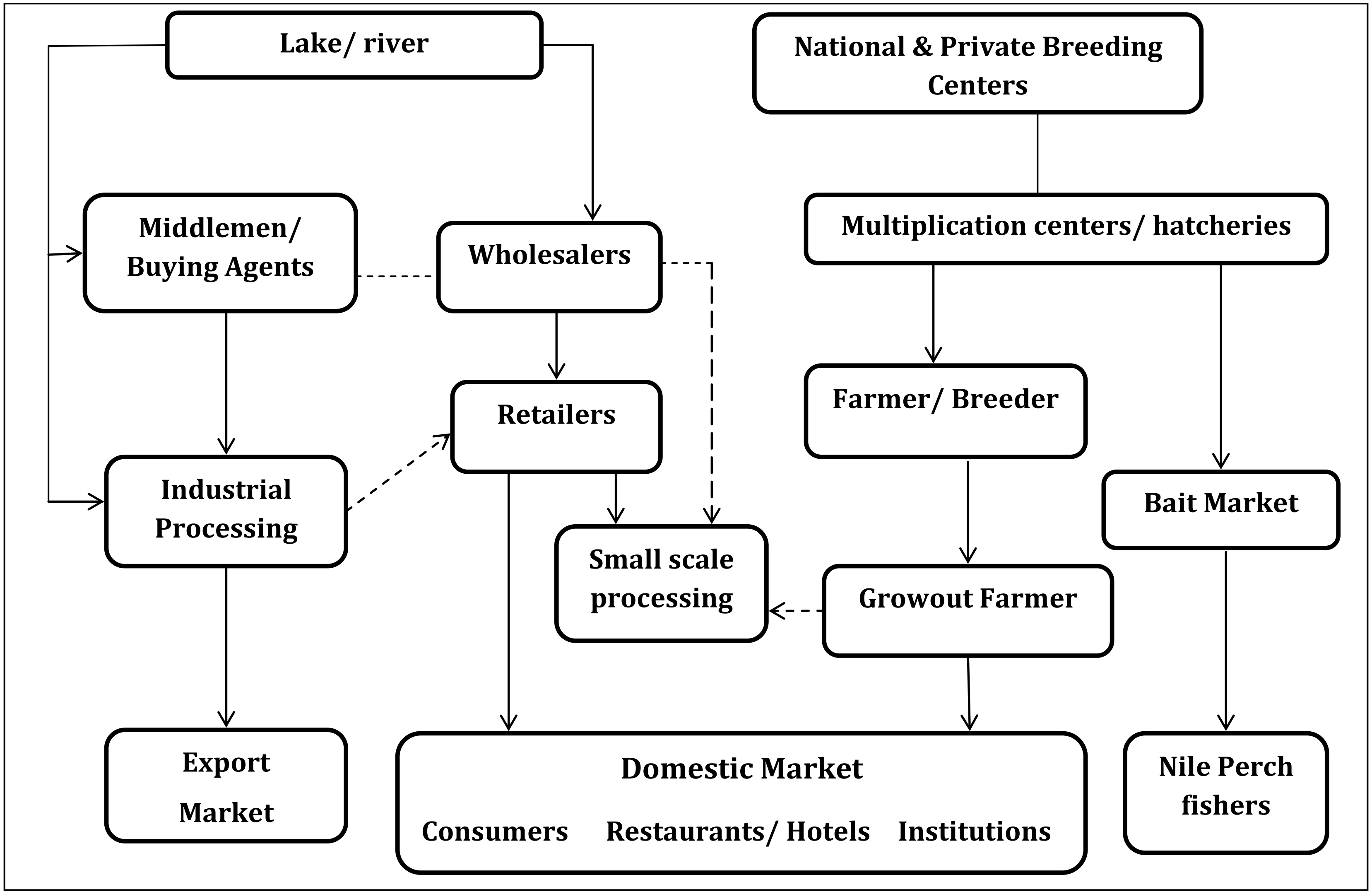
The initial findings have yielded some interesting results and more analysis is ongoing to account for indirect benefits. The high initial costs of fish farming in terms of land, training and construction needs to be addressed, despite government assistance through the ESP. This acts as one of the major constraints to increased female participation in the fish production stage.. The SWOT analysis of all supply chain actors indicates a need for more information sharing. The high ratios for Nairobi fish marketers suggest that close proximity to urban markets could improve farm revenues.

OBJECTIVE 5

The Fish Marketing Information System (FFMIS) was planned to tap into the existing Enhanced Fish Marketing Information System (EFMIS) operated by the Kenya Marine and Fisheries Research Institute (KMFRI). This EFMIS is a joint effort by KMFRI and the International Labour Organization (ILO). Initial cost estimates from KMFRI to develop a database for farmed fish as part of EFMIS was $100,000, which was unaffordable under this project's budget. Therefore, we piloted EFMIS with a select group of fish farmers. Fish farmers who were trained to query the EFMIS database to enable them become familiar with how the system works. The workshop was held at KMFRI offices in Kisumu where EFMIS is hosted and managed.

EFMIS was designed for providing market information to major landing beaches and has been expanded to cover over 140 landing beaches and urban markets. EFMIS releases market information principally on demand by text messages through a short code 5565. The system also disseminates synthesized market information through various media, including radio and the internet. The variables required for the system include fish quantities and prices at landing sites and inland markets, which is kept as a large database of market information, and updated on a daily basis. We have leveraged with the Fisheries extension network to set up similar structures that is capable of collecting daily data for farmed fish. With enough funding, it can be incorporated into EFMIS.

Figure 1: Flow Chart for Tilapia and African Catfish Products in Kenya



Adapted from Quagrainie, et al (2007), Charo-Karisa, et al (2007) and from survey findings

Table 1: Distribution and Descriptive Statistics of Respondents [a]

Variable		Mean	Std Dev
Gender			
	Female (1 = Yes)	0.542 (54.17%)	0.498
	Male (1 = Yes)	0.458 (45.83%)	0.498
Age (Years)		33.108	9.529
Married (1 = Yes)		0.725 (72.54%)	0.446
Household Size		3.826	2.247
Residential Status			
	Urban resident (1= Yes)	0.623 (62.34%)	0.485
	Sub-urban resident (1 = Yes)	0.377 (37.66%)	0.485
Highest Level of Education			
	Primary Education (1 = Yes)	0.260 (25.97%)	0.439
	Secondary Education (1 = Yes)	0.584 (58.434%)	0.493
	Tertiary Education (1 = Yes)	0.126 (12.62%)	0.332
	Post Graduate Education (1 = Yes)	0.030 (2.97%)	0.170
Monthly Household income ($)		342.209	185.504
Monthly Household Food Expenditure ($)		114.077	51.133

[a] Values in parenthesis are percentage of respondents.

Table 2: Results of the Ordered Logit Models [a]

	Tilapia Model	Catfish Model
Constant	-1.573 (1.134)	-7.581*** (2.161)
Female	-0.265 (0.427)	-0.845*** (0.060)
Married	0.040 (0.296)	0.005 (0.322)
Age	-0.004 (0.006)	0.007** (0.003)
Family size	0.065 (0.097)	0.0334 (0.042)
Urban residence	0.538*** (0.011)	-0.071 (0.138)
Household income	0.0005 (0.001)	-0.0002 (0.0002)
Secondary education	-0.069 (0.132)	-0.003 (0.219)
Tertiary education	0.657 (0.601)	1.262*** (0.309)
Post graduate education	-0.358 (1.037)	1.476*** (0.121)
Price of tilapia	-0.094 (0.119)	0.061 (0.091)
Price of catfish	0.063*** (0.019)	-0.237*** (0.086)
Taste	0.265 (0.230)	1.782*** (0.506)
Color	0.484*** (0.015)	0.766*** (0.184)
Smell	0.424*** (0.008)	1.007*** (0.011)
Nutritional value	0.272** (0.133)	0.100 (0.771)
Social status	0.308*** (0.083)	1.489*** (0.233)
Log likelihood function	-374.889	-262.903
Chi-squared	52.980***	318.867***
Pseudo R-squared	0.066	0.378

[a] Values in parenthesis are standard errors.
'***', '**', and '*', indicate statistical significance at 1%, 5%, and 10% respectively.

Table 3: Estimates of Random Parameters Logit Model [a]

Attribute	**Coefficient**	**Standard Deviation of Coefficient**
Price	-0.401*** (0.069)	
Farmed	-0.809*** (0.129)	1.273*** (0.319)
Medium	-0.255*** (0.086)	0.863** (0.439)
Large	0.571*** (0.118)	0.240 (1.115)
Fresh	2.934*** (0.462)	0.028 (0.516)
Fried	1.183*** (0.206)	3.303*** (0.701)
Smoked	-1.420*** (0.222)	0.118 (0.363)
Log Likelihood Fn.	-3359.92	
Chi-squared stat	2754.59***	
McFadden R^2	29.07%	
N	4312 = (539x8)	

[a] Values in parenthesis are standard errors.
'***', '**', and '*', indicate statistical significance at 1%, 5%, and 10% respectively.

Table 4: SWOT Analysis of Fish Farming

Strengths	Weaknesses
1. Improved food security- ready protein source 2. Source of water used for irrigation & livestock 3. Pond bottom mud used to fertilize gardens/fields 4. Source of water for household use 5. less labor intensive than other agriculture 6. Enhanced community relations- farm gate sales 7. Improved finances after harvest	**1. High initial cost for training, pond construction & inputs 2. Expensive to construction and operation costs 3. Require expert evaluation of location/site/water 4. Require training on fish rearing and pond management 5. Need expert for choice of fish species and appropriate culture 6. Require continuous access to expert for problem diagnosis & solutions 7. Supply of operating inputs 8. High labor demand for construction and harvesting 9. Scarce marketing information/access 10. Access to inputs for operating culture unit 11. Access to means of acquiring technical know-how**
Opportunities	**Threats**
1. Successful 2008 ESP government pond initiative 2. Increased local government financial support 3. Ready market due to government undersize fish ban 4. Branching into input supply &/or value addition 5. Change source of inputs-purchase, rent, or hire 6. Can diversify into ornamental or bait fish	**1. Access to capital 2. Seasonal patronage 3. Distance from farm to market 4. Low land availability 5. Need close proximity to water 6. High labor costs 7. Poaching 8. Unauthorized harvesting 9. Shortage of fingerling/fry to stock ponds 10. Lack of trained extension officers**

Table 5: SWOT Analysis of Input Suppliers

Strengths	Weaknesses
1. Low price **2. Convenient bulk sales** **3. One stop shop** **4. Only available option** **5. Quality** **6. Modern techniques** **7. After sale services/free consultation** **8. Sex reversal and genetic selection** **9. Training & Consultation on aquaculture** **10. Great service-personal touch** **11. Good marketing-flyers & demonstrations** **12. Liaisons with government -DOF referrals** **13. Connects supply chain actors** **14. Maintain specialization-cutting edge tech**	**1. Temperature control** **2. Expensive transportation** **3. Customer defaults on payment**
Opportunities	**Threats**
1. Only 6 government accredited aquaculture input suppliers **2. Well defined market with access to capital** **3. High entrepreneurial spirit** **4. More fish farmers- more customers** **5. Successful 2008 ESP government pond initiative** **6. Increased local government financial support** **7. Older fish farmers-retired from services** **8. Referrals from government for tech assistance** **9. Newcomer fish farmers in 30-50 age group** **10. More female fish famers-encouragement**	**1. More crime- higher incidence of con men, thefts and burglaries** **2. Strong US$ makes import expensive** **3. US$ fluctuations** **4. Increase in gas prices** **5. Customs and port delays** **6. Transport delays** **7. High nylon price-poor synthetic fiber** **8. Slow delivery of liners**

Table 6: SWOT Analysis for Fish Marketers

Strengths	Weaknesses
1. Can partake in wholesaling, trading and processing concurrently 2. Low start up and operating costs 3. Convenient bulk sales delivered to market 4. Can process (dry, smoke or fry) leftover fish 5. No construction or training required 6. Can assess quality and only sell good quality 7. Low switching costs in terms of products of location 8. Flexibility in terms of products sold 9. Flexible working hours 10. Can provide credit	1. Fish perishability-leftover & due to transport delays 2. High volatility in demand 3. Crime & Theft by middlemen & employees 4. Access to capital/finance 5. Transportation for fish supply, to market 6. No ice or electricity 7. Low profits-high buying and low selling prices 8. Expensive storage and refrigeration costs 9. Water shortage-increased costs 10. Storage problems 11. Poor shelter- rains in 12. Poor facilities including poor drainage
Opportunities	**Threats**
1. More Income- Nairobi markets 2. More female traders 3. More youth economic participation in market 4. More Consumers especially in City Market (Nairobi) 5. More female consumers 6. Better market conditions from government 7. Consolidation into one market facility 8. Constituency Development Fund made sheds 9. Improved sanitation (slight) including drainage 10. New farmed fish market	1. Less/no government assistance resulting in less customers due to filth 2. Poor roads-delayed delivery & accidents and having to no longer export to Tanzania 3. Fish shortage especially due to undersize fish policy and underdeveloped aquaculture sector 4. High cost of living-high inflation and income fluctuations 5. Poor economy, e.g. less income-less customers-low sales 6. Reduced Income- Western and Rift Valley regions 7. More crime & corruption- thefts and cheating customers and bribe requests by city councilmen 8. Supply fluctuations-Jun/Jul fish shortage crisis & Jan-Mar oversupply 9. Rainy season-fish doesn't dry well-bad business 10. Increased competition even from other markets 11. Poor hygiene in the market & transportation 12. High government taxes reduce profits 13. Low facility security

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Improving Supply Chain Opportunities for Tilapia in the Philippines

Marketing, Economic Risk Assessment, and Trade/Study/09MER03NC

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ABSTRACT

This study was designed to evaluate and develop an efficient tilapia supply chain to foster the development of viable fast food and supermarket purchases of tilapia from small-scale producers; with the following specific objectives. Phase 1 – Evaluation: (1) Develop tilapia supply chain maps for each market level, *i.e.*, producer, wholesale, restaurant, supermarket, fast food stores, etc., to identify specific activities and services, key players, logistical issues, external influences, and flow of product, information and payment among market levels; (2) Analyze tilapia supply chain performance for efficiency, flexibility and overall responsiveness; (3) Identify areas for improvement in supply chain, *i.e.* behavioral, institutional and process; and (4) Provide recommendations to improve the tilapia industry in general and its specific supply chain elements. Phase 2 - Development Undertaking: (1) Design specific improvement measures based on the identified areas of improvement from Phase 1; (2) Test the improvement measures in the market place, then assess and refine the improvement measures; and (3) Design and implement measures to ensure the sustainability of the improved supply chain of tilapia.

The country's tilapia industry supply chain is composed of the following parts: the hatchery and nursery farms which are responsible for the introduction of improved brood stocks to commercial or backyard fish farms, which in turn, are responsible in providing improved quality tilapia fishes for the end-users such as consumers and institutional buyers. The institutional buyers could be further decomposed into processors, consolidators or traders, supermarkets, specialty shops, food chains, restaurants, bars and canteens, among others.

The provinces of Pampanga, Batangas and Laguna are the major tilapia sources while the cities of Metro Manila, Angeles and Baguio are the major demand centers. Dagupan City, Pangasinan being known as "bangus" or milkfish capital is a major transshipment point of tilapia and other seafood for the Northern Luzon provinces including Cagayan Valley and the Cordillera Administrative Regions. In addition to the major supply center, Camarines Sur of the Bicol Region is becoming a key source of tilapia fries. The product flow of tilapia fries from the hatchery to the nursery farms generally follows a continuous 18-day cycle while tilapia fingerlings from nursery to commercial or backyard farms follows thirty- to forty five-day cycles depending on fish sizes required by the customers. Direct buying and selling, wholesaling, and retailing at central markets through agents and "consignacion" are the most common marketing operations of the tilapia industry. Consumers generally prefer whole live fish with size ranging from 250 – 300 grams per fish (or 4-5 pieces per kilogram) but the requirements of institutional buyers are more varied depending on their customers' preferences. Filleted tilapia requires about 2-3 pieces per kg or equivalent to 450 – 750 grams per fish. Grilled and barbequed tilapia are now becoming more popular recipes in the major demand centers.

The major concerns of hatcheries and nurseries are the high cost of outbound logistics, which is exacerbated by high competitive pressures of inferior quality but inexpensive stocks (e.g., non-sex reversed) and high levels of mortality due to environmental and cultural factors.

The fish farms' major concerns include expensive but low quality feeds (at times mislabeled) and other inputs as well as very low fish recovery and longer culture periods to attain larger fishes. Their transaction costs include the cost of waiting for buyers, delays in delivery, in-transit mortality, toll fees or "goodwill" as well as shrinkage losses. In addition, the lack of cold storage and transport vehicles equipped with tanks and aerators or refrigeration facilities delimits them from taking market opportunities. Interestingly, many farmers adopt a "circuitous" production technique to take advantage of markets preference of tilapia with darker skin.

The major concerns of processors are too few farms that could provide regular supply of the desired quality and volume of tilapia, the lack of capital for market expansion, and competition with cheaper imported counterparts.

The concerns of traders including "consignacion", suppliers or consolidators are: (a) meeting the product quality and quantity orders on schedule, (b) high logistics and transaction costs of consolidating and distributing fishes from sources to destinations, and (c) absence of product grades and standards.

The following are some recommendations to address the various issues and concerns of the various chain players: (1) encourage the establishment of more nursery farms for better quality brood stocks while intensifying technology transfer to farmers for better health and management of tilapia; (2) conduct market promotion activities highlighting the various niche opportunities of tilapia among growers and consumers; (3) motivate the participation of small farmers in supply chains by setting up an incentive scheme through a mix of patronage refund and profit sharing; (4) institutionalize an accreditation program for feed manufacturers, hatcheries, processors and the like to improve the quality assurance of products and services; and (5) provide capital windows to improve facilities and reduce logistics and transaction costs in the entire supply chains of tilapia.

INTRODUCTION

Tilapia culture is widely undertaken in the Philippines with regions III and IV of Luzon Island constituting the major production areas. Due to the product attributes and productivity as offshoots of research and development (R & D) efforts and programs beginning in the mid 80's, tilapia production has been a dynamic aquaculture enterprise in the country. Markets for tilapia remain vibrant with encouraging growth potentials. All major demand areas such as cities of Metro Manila, Baguio, Angeles, among others, are now preferring other product forms and shopping venues for reasons of convenience and availability than the traditional marketing mode.

Recently, efforts to sustain the industry's growth momentum have been focused on the genetic improvement of broodstock through cross breeding of different strains. Likewise, improved stock management and cultural practices have been developed to decrease mortality and to maintain growth vigor.

However, in the midst of the global economy, the tilapia industry remains sluggish with regard to serving new market niches such as supermarkets, food chains and exports. This is because small stakeholder producers that are scattered throughout the country dominate the tilapia industry. High mortality, small marketable body size and slow growth performance are still prevalent in the industry and this has limited expansion to new markets.

This existing condition of the tilapia industry amidst pressures brought about by global competition necessitates a development framework that views the industry in a holistic manner that would bring about visible and concrete improvements in production, handling and distribution processes or activities. It is of utmost consideration that the various players of the industry are coordinated to achieve a more efficient, cost-effective, profitable and sustainable industry that thrives in an environment of increased competition due to liberalized markets.

OBJECTIVE

This study was designed to evaluate and develop an efficient tilapia supply chain to foster the development of viable fast food and supermarket purchases of tilapia from small-scale producers. More specifically, objectives are organized as evaluation and development undertaking.

Phase 1 – Evaluation:
(1) Develop tilapia supply chain maps for each market level, *i.e.*, producer, wholesale, restaurant, supermarket, fast food stores, etc., to identify specific activities and services, key players, logistical issues, external influences, flow of product, and information and payment among market levels.
(2) Analyze tilapia supply chain performance for efficiency, flexibility and overall responsiveness.
(3) Identify areas for improvement in supply chain (*i.e.,* behavioral, institutional and process),
(4) Provide recommendations to improve the tilapia industry in general and its specific supply chain items.

Phase 2 - Development Undertaking:
(1) Design specific improvement measures based on the identified areas of improvement from Phase 1.
(2) Test the improvement measures in the market place, then assess and refine the improvement measures.
(3) Design and implement measures to ensure the sustainability of the improved supply chain of tilapia.

METHODOLOGY

This final report summarizes the literature review, methodology and project results. For more detail, see Jamandre et al. (2011).

Study Areas and Coverage

The study covered Regions III, IV and Metro Manila (*e.g.,* National Capital Region, NCR). In order to draw the major tilapia routes, at least one shipment in each of these regions, from the supply center to the ultimate end-user was traced.

Table 1 shows the total number of respondents covered, for each of the supply chains mapped. There are five chain players that perform either one process or a combination of processes depending on the degree of coordination in the chain, decomposed as follows: 5 hatchery and nursery operators, 28 farmers, 4 processors, 24 traders/consolidators/shippers and 11 institutional buyers.

Table 1. Number of respondents covered in the tilapia supply chains

Routes of SC mapped	Supply Chain Players	Number of Respondents
Bicol-Laguna-Batangas-Manila-Baguio (Chain 1):	Hatchery and Nursery Operators	3
	Fish farmers	15
	Processors	2
	Traders/consolidators	8
	Institutional buyers	5
Pampanga-Pangasinan-Ilocos and Isabela - Baguio and Manila (Chain 2):	Hatchery and Nursery Operators	2
	Fish farmers	13
	Processors	2
	Traders/consolidators	16
	Institutional buyers	6

Data Collection and Requirements

Primary data were obtained through survey, key informant interview and focus group discussions (FGD). FGD was also conducted to validate secondary information and to answer more specific questions related to supply chain mapping. A questionnaire was designed to answer key questions, among others:

Who are the key costumers and what are their product requirements (especially quality standards)?
Who are the key players and what are their respective roles?
How do product, information and money flow through the supply chain?
What are the activities and services provided at each level in the supply chain?
What are the critical logistics issues?
What are the external influences?

Secondary data series on tilapia statistics was obtained from various agencies such as the Bureau of Agricultural Statistics (BAS), Bureau of Fisheries and Aquatic Resources (BFAR) and other relevant agencies of the Department of Agriculture (DA). Previous studies on the production and marketing of tilapia also served as sources of secondary information (Jamandre et al. 2010). Likewise, Central Luzon State University and other relevant institutions served as sources of secondary information. Finally, officers and staff of appropriate government agencies and other industry personalities composed the key informants' pool.

The following primary data were collected: the key players and their respective roles activities and services provided at each stein the supply chain product requirements (especially quality standards) product, information and money flows critical logistics issues (including problems in production and marketing) extension services and external influences.

Data Processing and Analysis

Table 2 presents method of analysis for each objective. Areas for improvement in the supply chain were identified and specific policy recommendations were formulated with the end in view of improving the country's tilapia industry, through an improved supply chain management.

Table 2. Objectives and methods of analysis

Objectives	Methods of Analysis
(1) To provide an overview of the tilapia industry	Synthesis of relevant studies and trends
(2) To map out the specific supply chain for tilapia	Flowchart analysis from downstream to upstream
(3) Analyze the performance of the tilapia supply chain in terms of efficiency, flexibility and overall responsiveness	Descriptive statistics, and relevant performance metrics (both qualitative and quantitative)
(4) Identify areas for improvement in the supply chain such as behavioral, institutional and process	
(5) To provide specific policy recommendations to improve the tilapia industry in general, and the specific supply chain in particular	

RESULTS AND DISCUSSION

The Philippine Tilapia Industry: An Overview

In 2008, Philippines tilapia production was estimated at 299,813 MT (BAS 2009). Out of this, regions III and IV contributed about 80% while the rest of the regions shared the remaining 20%. The top 5 producing provinces (in descending order) include Pampanga (37.68%), Batangas (21.06%), Laguna (4.64%), Rizal (4.06%) and Bulacan (3.58%).

Important inputs to tilapia culture are the quality of seeds and broodstocks. With the efforts of Research and Development (R&D) agencies such as CLSU, BFAR, GIFT foundation among others, many hatchery farms were established across the country. However, despite the combined production outputs of the hatcheries the demand for fry and fingerlings exceeds supply. Many producers directly stock fry, while others adopt indirect stocking or stocking of fingerlings to limit higher mortality rates and longer culture periods associated with growout of fry (Tan et al. 2009). Those who stock fry directly utilize a higher density per m^2 than their counterparts. Those who stock indirectly require larger-sized fingerlings from mesh size 17-14, hence, offering opportunities for nursery operations.

Other inputs consist of capital investments such as the land, water supply system, drainage system, pump and supplies or equipment (seine net, weighing scales, tubs/buckets). Inputs also include the operating capital – fingerlings, fertilizer (chicken manure and ammonium phosphate), supplemental feeding (fry mash, fish starter, fish grower, fish finisher), labor, fuel/lubricant and electricity. Each item affects the operation of the tilapia industry particularly particularly with regard to feeds, which accounts for about 73% of the operating capital (BFAR 2010).

Marketing systems of tilapia in the Philippines is as varied as the locations of the supply sources. The traditional marketing of tilapia in some places is relatively simple. Traders normally pick up the harvested tilapia at the farms. Most tilapia farmers sell their produce to wholesalers-assemblers. Some sell their produce to retailers, consumers, and brokers. In Central Luzon, some distributors and retailers procure tilapia in *pakyaw* or bulk on an unsorted basis and these are hauled from the supply areas. Moreover, there are some traders that take charge in harvesting the produce and pay all the expenses during the activity. This practice is very common in the province of Pampanga (BFAR 2002). Some traders, particularly wholesalers, finance small-scale farmers in order to be assured of a steady supply of fish. Under this arrangement, the farmer is mandated to sell exclusively to the trader at a pre-agreed price. Major marketing issues for tilapia include fluctuating prices, irregular supply, nonpayment of debts by traders, informal levies (particularly when transporting the product), and seasonal off-flavors that render the fish less marketable.

Moreover, the supermarket phenomenon and more liberalized trading environment have induced the emergence of market niches such as the fillet, smoked, dried and other processed forms. Links with these new markets and increased participation of small-scale producers requires a new approach to tilapia marketing.

Key Customers and Product Requirements

The tilapia chain key customers are classified into two types: the institutional buyers (hypermarkets or restaurants/specialty food shops) and the household-level/end-users or consumers.

Product form

Generally, household customers prefer live whole tilapia with firm meat and with the size of 4-5 pieces per kg (200 - 250 g per fish). Also, regular tilapia consumers in Manila and Southern Luzon are indifferent relative to the source and skin color of tilapia. However, consumers in the Northern Luzon markets such as Pangasinan and Baguio exhibit similar product requirements except they prefer darker-skinned tilapia because they perceive that these fish have more belly fat and are tastier. The common food recipes for tilapia are charcoal grilled, fried, boiled and "*paksiw*". Most of these customers buy tilapia from fish vendors at local public markets or stalls. Regular customers in Laguna require daily volume of about 1,700 kg while Manila customers require 2,500 kg per day.

Institutional buyers such as specialty shops, hypermarkets or malls, restaurants and food chains cater to relatively affluent customers with varied product requirements. Hypermarkets normally require live whole fish with size from 3-4 pieces per kg (250 – 350 g per fish). Institutional buyers of this sort are indifferent to the source of tilapia as long as suppliers meet the fish size, volume and delivery requirements as stipulated in the marketing contract. Hypermarkets in Manila and Laguna normally require 500 – 1000 kg of tilapia per day while Pangasinan and Baguio require a daily volume of 65-70 kg.

In the case of specialty shops and food chains such as Monterey shops and SM South Mall, Central Barbeque Plaza in Parañaque and Ineng's Barbeque shop in Global City, tilapia fillet and whole frozen fish are more preferred than whole live fish. Specialty restaurants selling fish soups, tilapia belly and deep fried tilapia skin absorb by-products of filleting. The specialty shops require consistent fillet size and volume. The total volume requirement of these institutional buyers is 1000 kg daily with a fish size of 1-2 pieces per kg (450- 600 g fish).

Volume Requirement

The total volume requirements of the supply chains serving major customers in Luzon averages about 5,335 kg daily or approximately 1, 947,275 kg (or ~ 1,947.28 MT) annually. With the per capita consumption of around 3.81 kg (or ~ 323,850 MT), these chains could barely meet 1% of the consumption requirement of the country.

Major Players and Their Activities

The major players and their activities are highlighted in Figure 1. **Hatchery and nursery operators** supply fries and fingerlings as well as provide technical guidance to fish producer-customers. Both operators are closely linked and coordinated with each other. The hatchery handles about 3,000 breeders (Genomar crossed with IDRC strain) that produce 1.5 million sex-reversed fries every 18 days. The hatchery farms are located in Ligao City, Camarines Sur, which is around 600 km south of the nursery operator in Cabuyao, Laguna. Due to the travel distance, 33 plastic bags (i.e. imported from Taiwan) with no bottom corners, each containing 400,000 fries are used to reduce stress and minimize fry mortality

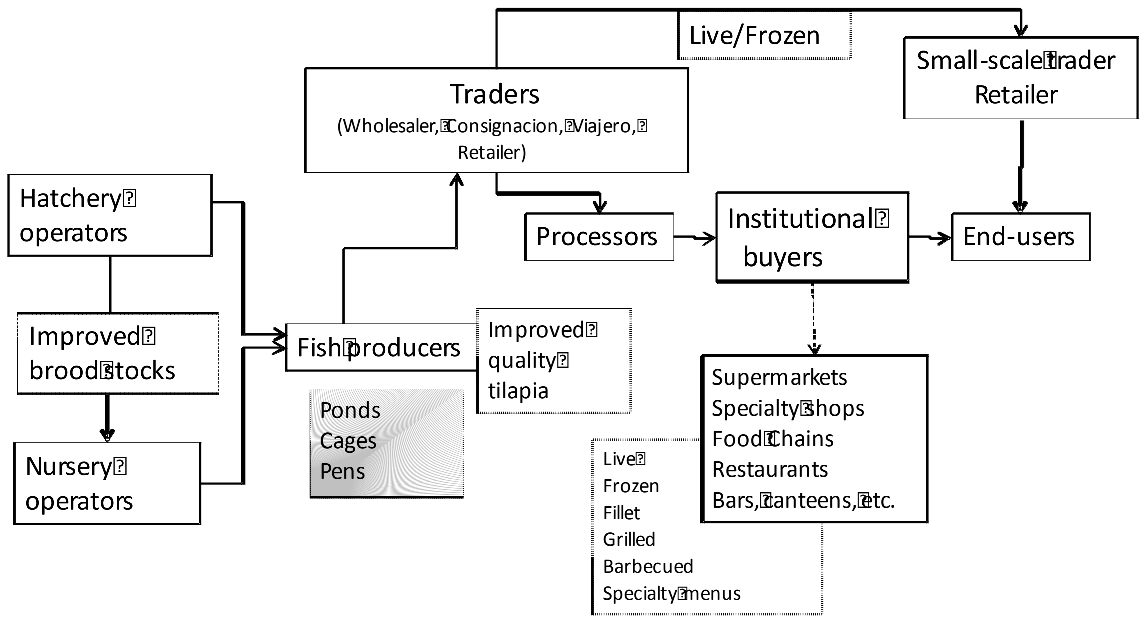

Figure 1. Major Players and their Activities

while being transported in 4 rented trucks each with 6-ton capacity. Oftentimes, the **hatchery operators** pay "goodwill fees" to traffic enforcers on top of the regular toll fees charged by the superhighways in Manila. The operators also maintain nursery ponds to serve other farmer-customers requiring bigger fingerlings in nearby towns of Buhi, Baao and Bato, Camarines Sur. These customers usually also require 400,000 fry every 18 days. Normally, the hatchery operators charge P0.05 higher than other competitors in the area because fry are already sex-reversed. Upon reaching Laguna, delivered fry are immediately unloaded to the conditioning pond for acclimatization. The nursery operators manage and maintain the fry until reaching marketable sizes of 14 and 12 as ordered by regular producer-customers (chain members) in Laguna and Batangas. Normally fry are maintained for 1 month and then it takes an additional 3-4 weeks to reach size 14 for sex-reversed fingerlings. Otherwise it takes 1 and 1½ months for non-sex reversed fish. The nursery ponds handle various tilapia strains since the regular customers tend to try other strains in their operations. Usually, the **nursery operators** deliver fingerlings 4 times per week to their regular customers. Also, the sizes of fingerlings delivered vary with "season" i.e. smaller size (22-20) during on-season months (May, June, July, August) while 14-12 on off-season (September, October, November, December). Finally, the nursery operator prefers tilapia nilotica as a better species compared with other tilapias.

The **fish producers** are the main "production centers" of the tilapia chain whose focus is to produce marketable tilapia for distribution through traders for end-users or consumers and processors for institutional buyers. The regular producer-customers usually take 2.5 – 3 months to grow their fishes to reach marketable size of 4-5 pieces per kg and about 3.5-4.5 months to reach 2-3 pieces per kg. **Fish producers** (chain-members) are aware of the product, volume and delivery requirements of their trader-customers. To reach markets in the Northern Luzon which prefer darker colored skin tilapia, fish producers grow the tilapia first in Laguna under semi-extensive feeding regime, say 2-3 months, then transfer the fish to Taal Lake in Batangas for conditioning, say in 3 weeks before harvest – a kind of "circuitous" production technique. Most **fish producers** do not have delivery trucks and facilities for cold storage. Thus, they have to wait for their customers to haul their fish harvests from the farm site. Other producers (non-chain member) in Laguna and Batangas persist to stock non-sex reversed fingerlings since it is cheaper and it performs at par with sex-reversed counterparts as they claim, although it takes a longer time to reach equivalent weights or sizes to that of sex-reversed fingerlings. Hence, these producers are losing more in terms of low fish recovery of about 18-20% in Laguna Lake and 25-30% in Taal Lake. Additionally use of non sex-reversed fingerling results in higher feed costs. Occasionally, customers of non-chain members complain about the off-flavor taste of their tilapia. Accordingly, farmers' knowledge on preventing repeat of such incidents is fairly limited.

Traders generally subsume the terms **consolidators/wholesalers/retailers** and brokers or agents a.k.a. **consignacion** since they are all engaged in the buying, selling and distribution of tilapia from sources to various destinations depending on which market level they operate. The **consolidators** are the big traders who regularly supply supermarkets and bulk buyers in major fish terminal markets (or transshipment points). At the terminal markets, the "**consignacions"** facilitate the transactions between the traders (shippers or viajeros) and bulk buyers (provincial traders) for a "commission fee". Since they own a stall at the terminal market, they also act as gatekeepers of the traders and are key players in the price discovery process, thus, they also perform price monitoring and occasional small-scale trading. The **wholesalers** are themselves shippers or viajeros who buy tilapia from the terminal markets in bulk and ship them to other bulk buyers serving other geographical markets. Strategically, some wholesalers resort to backward integration by producing their own tilapia and contracting other farmers to meet market commitments and reduce supply risks. The **retailers** are the smallest traders in the market chain that finally cater to the end-users. They own stalls at public markets and small delivery vehicles such as tricycles and owner jeeps with aerators. Their sales volumes depend on the deliveries by local traders. Since they compete with many retailers, they handle about 100-150 kg of live fish (with average size of 5-6 pieces per kg) for easier disposal and to minimize unsold products for each transaction day.

Processors are those who regularly supply the specific product forms such as the fillet, cubes, whole frozen and choice portions or trimmings for institutional buyers (supermarket, specialty food shop, food chain, bar and restaurants, canteens, among others). One big processor, known as Fishda Enterprises, had been operating and registered in 1995. This **processor** has been incorporated and now named as Unavis. Its operation is accredited by Department of Food and Drugs. Product forms, volumes and deliveries depend on the arrangements with the various customers. Presently, the customers include Monterey specialty shops, SM Southmall, Metro Bank canteens, Central Barbeque Plaza in Parañaque, Ineng's Barbeque at Global city, Setton Golf Club, etc. To maintain its customers, the **processor** ensures that raw materials meet the size, volume and meat quality requirements needed for processing. The processing plant has 1.5 - 2 ton capacity (processing-in -demand) with 6 – ton cold storage capacity of filleted tilapia. The plant maintains a safety stock level of 5 tons. The filleting process for a per kilogram raw tilapia (2-3 pieces per kg) yields the following: 30-35% fillet, 18% belly, 25% innards, 21% head and 1% skin. Because the cost of filleting is about P35 per pack (1 pack = 300 grams), cost recovery is taken from the sales of the by-products. The **processor** could not raise the price of tilapia fillet due to cheaper import alternatives like the pangasius and dowry fillets. To increase the shelf-life and maintain quality of products, quick or blast freezing is necessary. Increasing the present capacity of cold storage and blast freezers entails additional costs, which is unaffordable at the moment. Finally, only few tilapia producers can meet and assure volume, size and quality of raw materials, thus, the processor cannot expand market coverage. Many orders and inquiries from potential high-end customers including Philippine Airlines, Cathay Pacific, five star hotels and restaurants, etc. are not met.

Major Routes of Products

Figure 2 shows the tilapia supply chain's major routes in Luzon. The cities of Malabon in Manila, Angeles in Pampanga and Dagupan are the major transshipment points of tilapia in Luzon. Cities in Metro Manila, Angeles and Baguio, La Union and Ilocos provinces, Isabela and Cagayan Valley provinces and the Cordillera Administrative Region, are the major demand centers. Pampanga, Batangas and Laguna provinces are the major production centers while Pampanga, Laguna and Camarines Sur possess the major hatcheries.

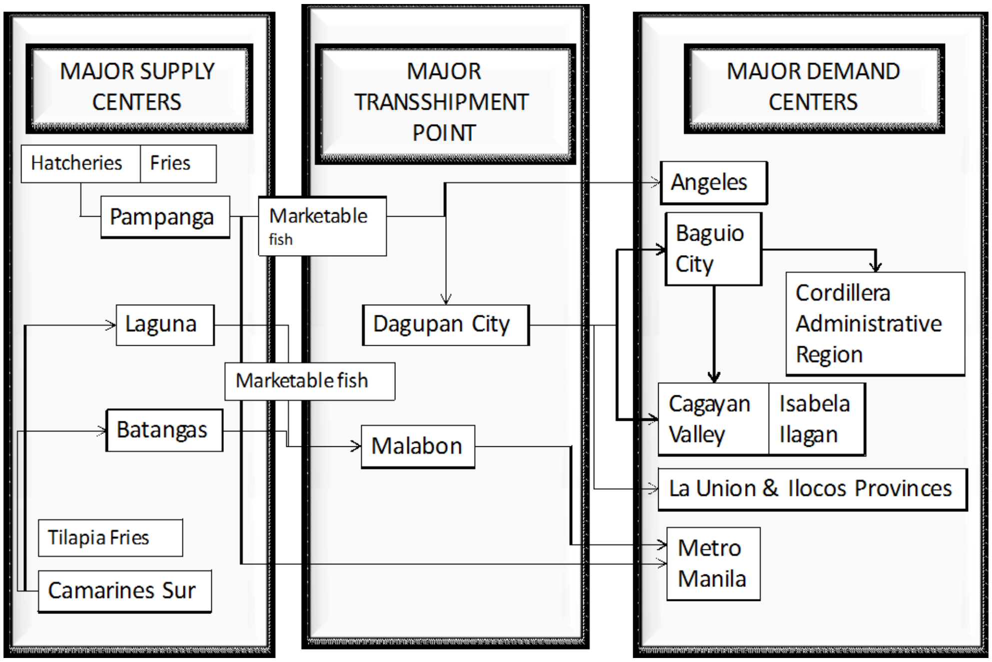

Figure 2. Major Routes of Products

The geographical locations of the major routes are mapped in Figure 3. There are two major routes traced namely: (1) Laguna/Batangas – Manila/Baguio; (2) Pampanga – Pangasinan/Baguio. These routes normally take from 1 to 3 days to distribute from source to final destination points. The time period used to assemble the required volume of tilapia with consistent size is the bottle neck for meeting the entire delivery schedule.

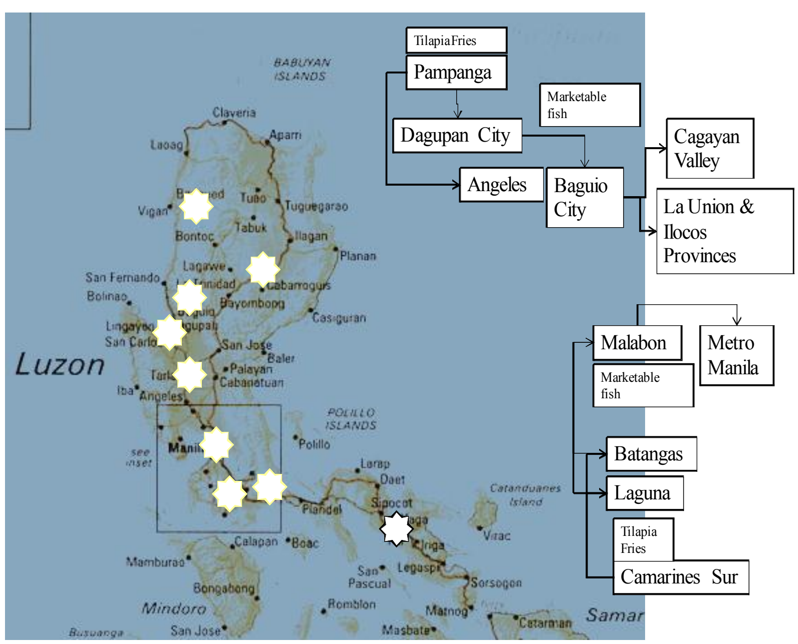

Figure 3. Major routes of the Tilapia Supply Chain

Figure 4 describes the product flow of route 1. Eighteen-day old tilapia fry from Camarines Sur hatchery are brought to the nursery operators in Cabuyao, Laguna for conditioning and growth for about 45 days to reach fingerling size of 14-12. The fish are then be delivered to grow-out operators in Laguna and Batangas for 2-3 months before harvest. Fish sizes range from 4-5, 3-4 and 2-3 pieces per kg. Small fishes are sold to local markets in Los Baños and Pila, Laguna. The larger fishes are delivered to supermarkets in Calamba and Sta. Cruz, Laguna. Largest fishes are delivered to the processors in Los Baños, Laguna and Parañaque. Fishes intended for the Northern Luzon supermarkets such as Rosales, Pangasinan and Baguio City are transferred and conditioned in Taal Lake for a period of 3-4 weeks to ensure that fishes have dark-colored skin before marketing.

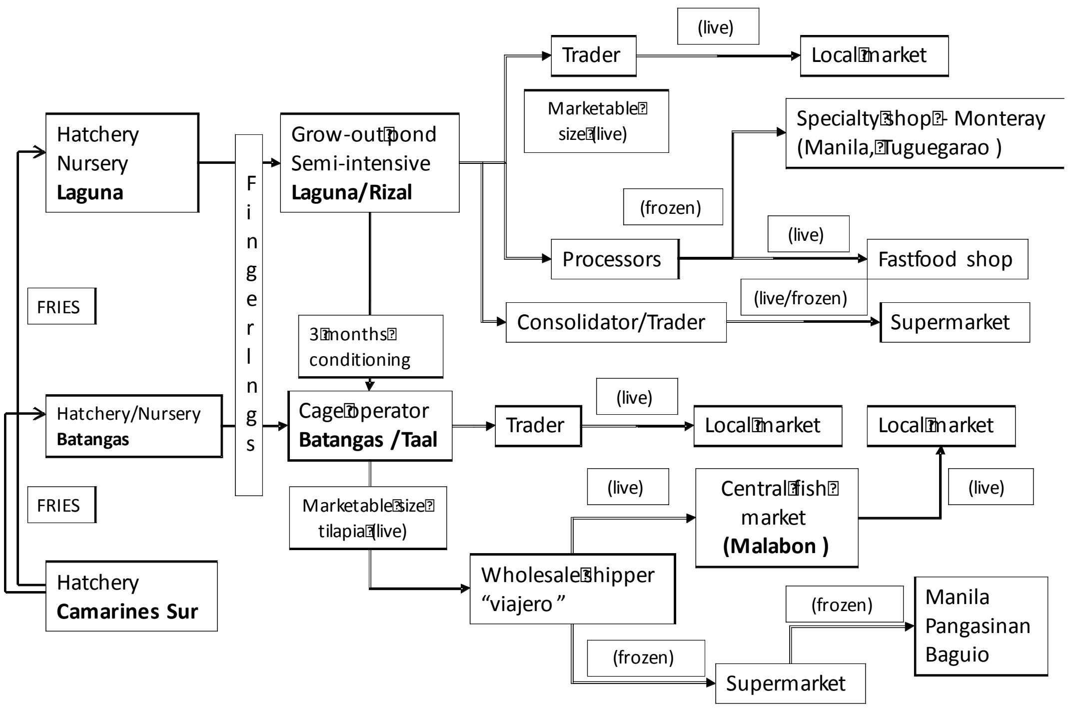

Figure 4. Product Flow (Laguna/Batangas-Manila/Baguio-Route 1)

In the case of Batangas, fries with size 22-20 from Calauan, Laguna hatcheries are brought to grow-out operators in Tanauan, Talisay and other towns along the Taal lake. Large fish producers (with 500 cages) within the supply chain in Batangas usually stock 200 fish/m^3. Their fish recovery in Taal lake ranges from 25%-30%. Furthermore, their feed conversion ratio (FCR) on the average is 1.5:1 while Laguna producers show even lower FCR. After 6-8 months culture period, marketable tilapias are picked up by wholesalers and brought to Malabon, in Manila, being the major transshipment point for seafood that caters to markets in Metro Manila and the rest of Luzon. Smaller traders and other provincial traders both procure their fishes from wholesalers through a consignacion in Malabon market. Fishes are then packed in iceboxes for distribution to supermarkets and far-flung markets.

The flow of products in route 2 is shown in Figure 5. Pampanga fish producers usually obtain their fry from nearby hatcheries and stock them directly in their grow-out ponds. After a 6-8 month culture period, tilapia are harvested using mesh nets since pond sizes range from 2-12 hectares. Some larger farms have about 25-100 hectares surface areas. Most farmers do not have trucks equipped with tanks and aerators, thus, they have to wait for traders through an agent to pick up their harvest and bring the fish to the terminal market in Pampanga, Angeles City as the major transshipment point of Pampanga.

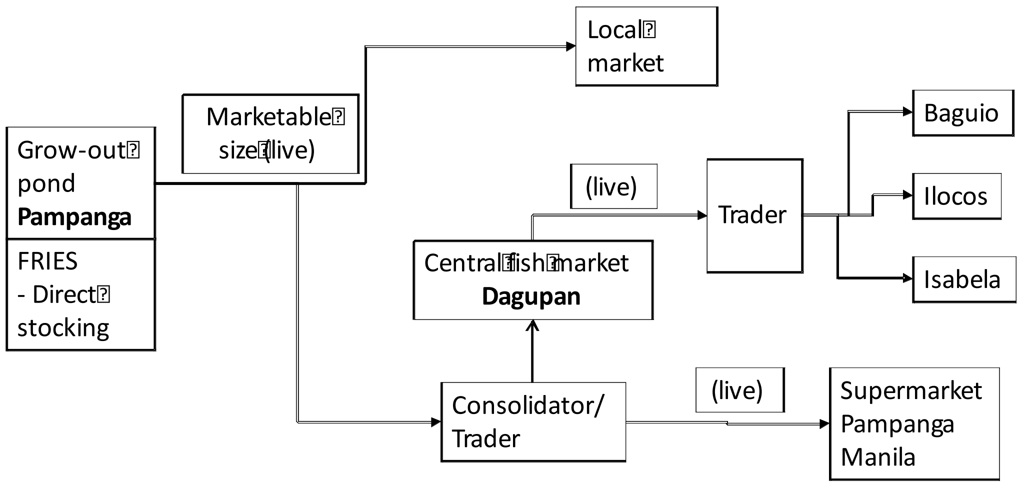

Figure 5. Product Flow (Pampanga-Pangasinan/Baguio-Route 2)

Wholesalers and local traders including consolidators source their live tilapia at this market. Wholesalers bring their tilapia to the consignacion market in Dagupan City, Pangasinan serving as transshipment point for the rest of the Northern Luzon markets. Fishes usually reach this market alive, which is preferred by most, if not all, customers. However, once passed on to other provincial traders whose markets are farther, fishes must be stacked with ice to retain freshness upon reaching destination points. Normally it takes around 1-2 days to reach some markets in Ilocos and Isabela provinces together with Cagayan Valley and Cordillera Administrative regions.

Payment Flow

In general, payments are made on spot cash and cash-on-delivery (COD) between the local consumers and retailers; wholesaler and trader/consolidators; processor and producers; small-scale traders and producers. However, bank payments through 7 day post-dated checks are made among hatchery/nursery operators and producers; supermarket and processors/traders or consolidators (Figure 6).

Only the specialty shops make advanced payments to the processor for about 1-2 days before product delivery, as stipulated in a contract. On the other, the traders/consolidators who loan out feeds to producers and provide trading capital to small-scale traders adopt a different payment arrangement. The small scale-traders check on the exact harvesting dates of the farmer-borrowers. Upon harvest, these traders weight, transport and consign the tilapia harvest to the local retailers at an agreed price. After each transaction day, the retailers remit the net sales proceeds to the small-scale traders who in turn remit the same plus the trading capital equivalent to the fish volume purchases from the producer-borrowers to the trader/consolidator. After deducting the cost of feeds, the trader pays the producers the net sales value of their tilapia.

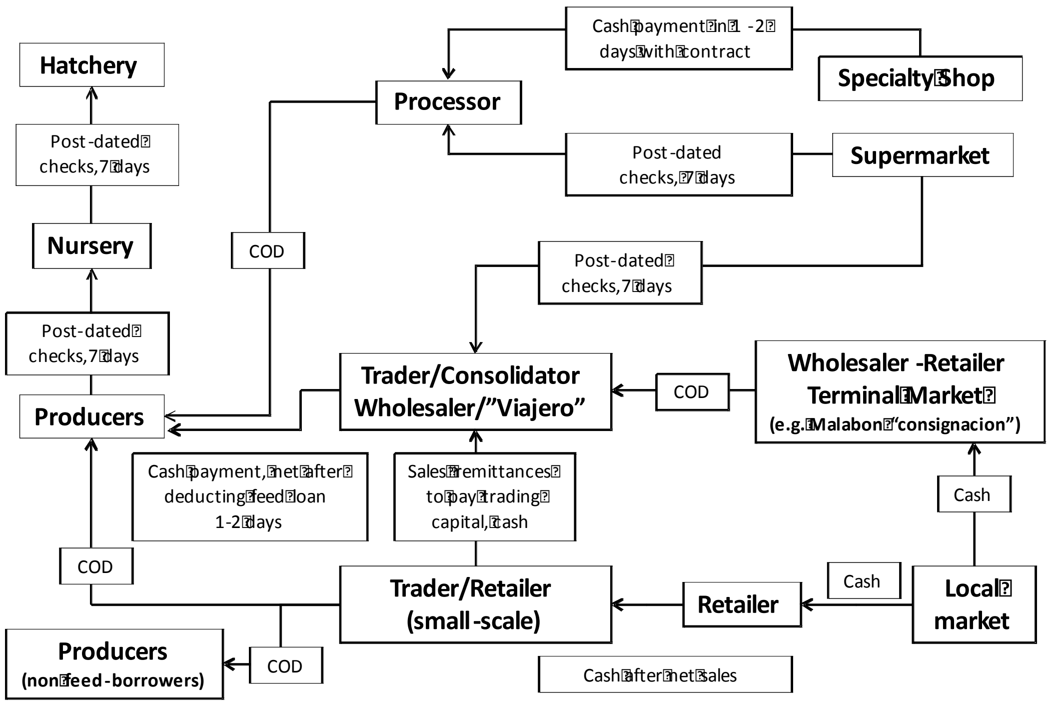

Figure 6. Payment Flow of the Supply Chains

Information Flow

Figure 7 shows the flow of information among the supply chain members. Information exchange between and among the chain members and the mode of contact are done through face-to-face and mobile or telephones which are concluded in a short period of time. The price, sources, quality, availability and delivery schedules of tilapia are the major information required by the chain members. Farm gate prices are lower and more unstable than those in the wholesale and retail levels. Such behavior is prevalent because institutional buyers are slow to react with price changes. Additionally, the processor maintains a price level of two years ago for fear of losing customers with or without contracts. Retail prices tend to be sticky upwards but faster to adjust downwards.

External Influences

(1) Production and market support programs of the government

Recognizing the importance of tilapia to address poverty alleviation and development of the country side, the government has embarked on a tilapia upgrading program through genetic improvement projects espoused by CLSU, GIFT, BFAR and other international R&D agencies. This program had effected the participation and entry of many tilapia industry players. Additionally, the establishment of hatcheries and dispersal programs of BFAR had facilitated the extension of broodstock quality improvement of tilapia into the countryside. Likewise, training and capacity-building among tilapia farmers has been implemented. The training includes improved technologies in management, nutrition and health aspects of tilapia culture. The continuing improvement of broodstock and dispersal program will help foster the growth of the industry. On the other, the market support program of the government of the Philippines (GOP) is limited to market matching and participation in aqua fairs.

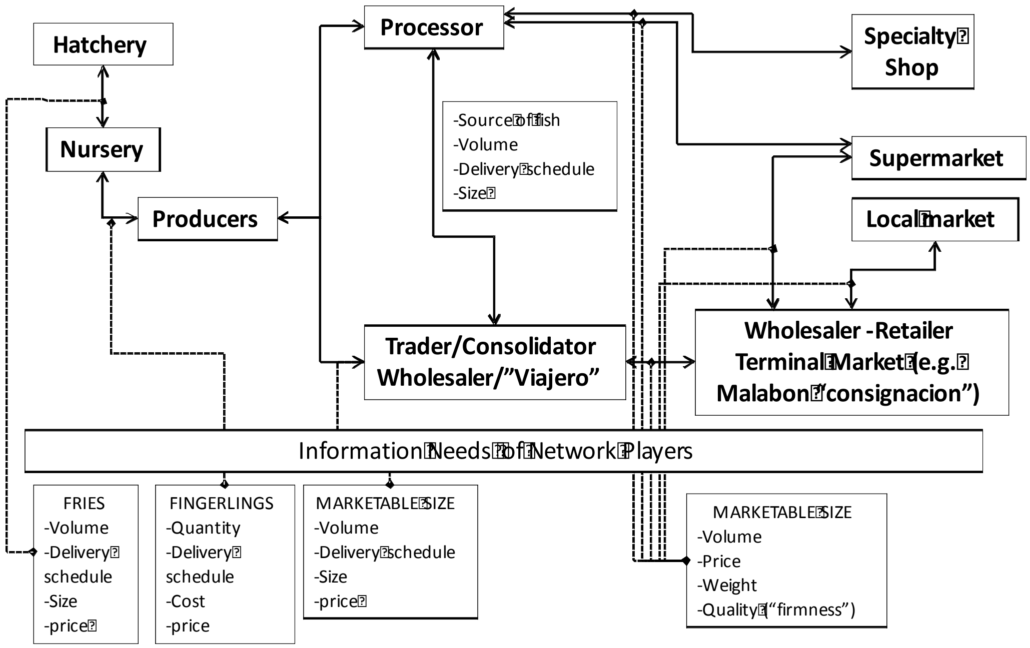

Figure 7. Information flow of the supply chains

(2) Food safety through permits and accreditation

In preparation for globalization, BFAR has instituted an accreditation protocol for quality assurance of meeting export standards. However, many found it to be very rigid which restricts the potential exporters to qualify. Unfortunately, fish imports continually flood the domestic market which dampens further the competitiveness of the local industry.

(3) Presence of "rent-seeking" behavior of law enforcers

In addition to the toll fees in superhighways paid by traders or viajeros including hatchery operators, *unreceipted* fees are charged that serve as goodwill to rent-seeking law enforcers at check points. Such expense is usually passed on to the final consumer.

Issues and Concerns

The major concerns of hatcheries and nurseries are high cost of outbound logistics, which is exacerbated by high competitive pressures of inferior quality but inexpensive stocks (e.g., non-sex reversed) and high levels of mortality due to environmental and cultural factors.

Fish farmer concerns involve a broad array of production, processing and marketing constraints. Feeds and other inputs are often expensive but low quality (at times mislabeled) and there is very low fish recovery of about 25% in lakes' cages or pens and about 60% in ponds system. In addition, the more pronounced fluctuations in climate pattern has induced more variability in production volume hence, overstocking became a "recouping mechanism" among fish growers. Contrary to research and extension trials and demonstrations, grow-out period for farmers often are much higher – ranging from 6-8 months to reach a marketable size of 250-400 grams per fish across production systems. Their transaction costs include the cost of waiting for buyers, delays in delivery, in-transit mortality, and "goodwill" or toll fees as well as shrinkage losses. In addition, the lack of cold storage and transport vehicles equipped with tanks and aerators or refrigeration facilities delimits farmers to take market opportunities in terms of value-adding and processing activities. Interestingly, due to the high consumers' preference on "darker tilapia", many farmers adopt a "circuitous" production technique, that is, fry from the hatcheries for example in Bicol (pond based) are transferred to nursery ponds in Cabuyao, Laguna then moved and raised in a semi-intensive grow-out environments in Laguna Lake and finally transferred and conditioned as "dark tilapia" within 3 weeks in another place like Taal, Batangas to take advantage of such marketing premium. This apparently inefficient production scheme is rational if consumers provide a sufficient price premium.

The major concerns of processors are too few farms that could regularly supply the desired quality and volume of tilapia at each process-in-demand period. Likewise, there is a lack of blast freezers to maintain higher quality products while maintaining longer shelf-life of products and other derivatives. In addition, due to high cost of filleting and low dressing recovery, processors are at a disadvantage in competing with the influx of cheaper imported alternative fillets like pangasius, sea bass and others, saved by the revenues derived from by-products such as heads, bellies and skin. Demand for choice portions and trimmings by high-end institutional buyers like Philippine Airlines and Cathay Pacific remain untapped. Also, tilapia nuggets and fingers are test markets that have not been met, yet show bright prospects.

The concerns of traders ("consignacion", suppliers or consolidators) are: (a) regularly meeting the quantity and delivery schedules of their customers is undermined by their defaulting "contract tilapia farmers" (b) high logistics and transaction costs of searching, locating, assembling and distributing fishes from sources to destinations (c) lag responses in unexpected price movements and the absence of product grades and standards contribute to the difficulty of maintaining a "profitable" volume of operation.

RECOMMENDATIONS

Specific improvement measures have been designed, refined and implemented based on this market supply chain analysis (Phase 2). Improved sustainability and efficiency have been achieved through many of the programs outlined in the previous section and continued improvements recommended as a result of this study that address the issues and concerns of the supply chain participants include: (1) encourage the establishment of more nursery farms and better quality broodstock while intensifying technology transfer to farmers for better health and management of tilapia, (2) conduct market promotion activities highlighting the various niche opportunities of tilapia among growers and consumers, (3) motivate the participation of small farmers in supply chains by setting up an incentive scheme through a mix of patronage refund and profit sharing, (4) institutionalize an accreditation program for feed manufacturers, hatcheries, processors and the like to improve the quality assurance of products and services, and (5) provide capital windows to improve facilities and reduce logistics and transaction costs in the entire supply chains of tilapia.

The results of the supply chain analyses was presented to Philippine government officials of the Bureau of Fisheries and Aquatic Resources as well as to producers, manufacturers, other industry representatives and to the academic research and extension community through a workshop held at CLSU entitled "Tilapia Feeds and Feeding Strategies: Meeting Global Challenges". Findings were also disseminated through presentations at the 9th Asian Fisheries and Aquaculture Forum - 9th International Symposium on Tilapia Aquaculture (Shanghai, China) and at the 23rd Agency In-house Review of Completed and On-going Research and Development Projects at CLSU.

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Value Chain of Snakehead Fish in the Lower Mekong Basin of Cambodia and Vietnam

Marketing, Economic Risk Assessment & Trade/Study/09MER04UC

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TABLE OF CONTENTS

Part **Page**

PART I: INTRODUCTION 198

1.1. .... Background 198

1.2. .... Research Objectives 199

PART II: RESEARCH METHODOLOGY 200

2.1. .... Scope of the Study 200

2.2. .... Methods of Data Collection 200

2.3. .... Methods of Data Analysis 200

PART III: VALUE CHAIN OF SNAKEHEAD FISH IN CAMBODIA 202

3.1. Description of chain actors of snakeheads 202
3.1.1 Small-scale fishers of snakeheads 202
3.1.2 Farmers of snakehead fish 205
3.1.3 Traders of snakehead fish 208
3.1.4 Processors of snakeheads 210
3.1.5 Consumers of snakeheads 212
3.2. Marketing channels and Cost-Benefits distribution of chain actors in Cambodia ... 214
3.2.1 Marketing channels of chain actors for snakehead fishers 214
3.2.2 Cost-Benefits distribution of chain actors of captured snakeheads 215
3.2.3 Marketing channels of chain actors for cultured snakeheads 215
3.2.4 Cost-Benefits distribution of chain actors for cultured snakeheads 216
3.3. Major suggestions for upgrading the value chain of snakeheads in Cambodia 216

PART IV: VALUE CHAIN OF SNAKEHEAD FISH IN VIETNAM 218

4.1. Description of chain actors of snakeheads 218
4.2. Marketing channels and cost-benefits distribution of chain actors 221
4.3. .... Major suggestion for upgrading the value chain of snakeheads in Vietnam 222

PART V: CONCLUSIONS 224

5.1. .... Value chain of snakeheads in Cambodia 224
5.2. .... Value chain of snakeheads in Vietnam 224

REFERENCES 226

LIST OF ABBREVIATIONS

CTU	:	Cantho University
FGD	:	Focus Group Discussion
FiA	:	Fisheries Administration
G	:	Gram
GIZ/GIZ	:	Deutsche Gesellschaft für Technische/Intenational Zusammenarbeit
HH.	:	Household
IFReDI	:	Inland Fisheries Research and Development Institute
Kg	:	Kilogram
KIP	:	Key Informant Person
LMB	:	Lower Mekong Basin
MRC	:	Mekong River Commission
M4P	:	Making Markets Work Better for the Poor
NAV	:	Net Added Value
NGO	:	Non-Government Organization
P.	:	Pangasius
USD	:	The United State Dollar
VND	:	Vietnamese Dong
WF	:	WorldFish Center
%	:	Percent
/	:	Per

Part I
Introduction

1.1. BACKGROUND

The Lower Mekong Basin of Vietnam and Cambodia are lowland areas and famous with wetland ecosystems where freshwater resources (Appendix Figures 1.1). Fish constitutes about 75% of the animal protein intake for the Cambodian households and most of it comes mainly from freshwater fisheries in both fresh and processing form (Hap, 1999). Cambodia is considered to be the most productive inland fisheries of the world, contributing around 60% of the country commercial fisheries production (Ahmed et al., 1998). Approximate 70% of animal protein intake for Vietnamese in the Mekong Delta is from fish and Vietnam ranks third in the word on the fish production (Ministry of Fisheries, 2005).

Besides inland fisheries, aquaculture, which contributes around 10% of the total inland fish catch, also plays an important role and is considered to have great potential for augmenting fish production in Cambodia (Rab et al., 2006). Moreover, fisheries and aquaculture is believed to have enormous potential to provide the poor people with more food, better nutrition and increased incomes. They also stimulate economic growth and offer greater diversification of their livelihoods (WF, 2008). Inland fisheries still keep the key role to fishery sector in Cambodia while aquaculture becomes more important in Vietnam.

Within the freshwater aquaculture model in Cambodia, cage culture represents the highest percentage of about 70% of aquaculture production while pond culture covers only 30%. The most important and high profit fish species in cage culture system in Cambodia is Chhdaur (Giant Snakehead, *Channa Micropeltes*) (So et al., 2005). Giant snakehead is commonly raised in cages in and along the Mekong River, the Great Lake Tonle Sap and Tonle Sap River (Hap and Pomeroy 2010). As originated in Cambodia, cage culture increased to 4,493 cages in 2004 being operated in the Mekong Basin, including the Tonle Sap Great Lake (42%), the Tonle Sap River (17%), the upper stretch of the Mekong River (19%), lower stretch of the Mekong River (14%) and Bassac River (7%) (So et al., 2005). Moreover, in Cambodia cage culture of giant Snakehead was started in 1990s. During 1991 to 1993, there were only a few of households who were interested in culturing giant snakehead, but from 2001 to 2005, this numbers increased very fast throughout the country such as in the Great Lake Tonle Sap, along Tonle Sap River, Mekong and Bassac River (Hap et al., 2006). From 2005, Cambodian government issued the ban on farming of snakehead fish due to the fear of depletion of wild fish resources.

For several decades, aquaculture in the Mekong Delta region of Vietnam has played an important role to the delta community through improvements in the provision of animal protein, creation of jobs, and generation of income, as well as contribution to the domestic consumption and exports of aquatic products of Vietnam. The Delta produces more than 73% of total fish production of the country (General Statistic Office, 2010). There is an increasing growth in freshwater aquatic production that includes catfish (tra and basa fish), tilapia, anabas, snakehead, and freshwater prawn. The farming of snakehead fish, especially common snakeheads (*Channa striata*), a popular freshwater fish species, has rapidly spread in Vietnam with five common models, including: earth ponds, floating ponds (also known as canvas or concrete tanks), hapas in ponds, hapas on rivers, and floating cages on rivers (Le Xuan Sinh & Do Minh Chung, 2009). Snakehead are mainly cultured in small-scale farms with high stocking density and fed by low value fish or trash fish, which can help reduce poverty (Le Xuan Sinh et al, 2009). In addition, pressures on wild snakehead have been reduced through successful artificial reproduction and farming of this species. Long (2004) reported that the production of snakeheads in the delta was 5,300 tones, mainly in An Giang, Dong Thap, Long An, Can Tho and Kien Giang provinces. In 2010, the summary from annual reports of the delta provinces showed that the snakehead production was 40,000 tons; this is an increase of about 10,000 tons from 2008 production.

Fish products from cage culture were sold to domestic and international market in both fresh and processed forms (Hap et al., 2006). Snakeheads for human consumption in Cambodia are mainly from wild fish capture. Wild captured snakeheads are traded via the border of Cambodia and Thailand while cultured snakeheads are imported from downstream areas of Vietnam in a small proportion (Loc et al., 2007; Le Xuan Sinh & Do Minh Chung, 2010).

However, the rapid development of snakehead aquaculture has led to economically unstable conditions. The farming systems of snakeheads have been spontaneous and mainly uses live feed such as fresh trash fish, marine fish, yellow apple snails that cause environmental pollution and the depletion of natural aquatic resources in freshwater. The price of commercial snakeheads is not stable because they are strongly affected by the seasonal supply of wild captured fish as well as seasonality in snakehead farming while they are mainly used for domestic consumption (Sinh et al, 1998; Le Xuan Sinh & Do Minh Chung, 2010). The farming of many fish species heavily depends on wild indigenous fishes both for seed and feed while the wild fish stock in freshwater bodies of the delta has been rapidly depleted due to many reasons (Sinh, 2005). There has not been much research conducted on snakeheads, especially the marketing of this group of fish species. So far, market channels as well as value chains of giant snakeheads and common snakeheads have not been studied. Therefore, it is a need to conduct a study covering all of the aspects of snakehead fish industry in the Lower Mekong Basin. The results of this study will be useful for management and any further development of snakehead industry, as well as contribute to the food security, job creation and marketing of fish products in the Lower Mekong Basin region of Cambodia and Vietnam.

1.2. RESEARCH OBJECTIVES

The general objective of the study is to conduct value chain analyses of snakeheads in the Lower Mekong Basin of Cambodia and Vietnam in order to propose major solutions for a further development of snakehead industry with the regards given to upgrading the value chains of captured and cultured snakeheads.

The specific objectives are:

1. To describe and analyze the situation of chain actors participating in snakehead industry;
2. To analyze the cost-benefit distribution of chain actors; and
3. To propose improvements for upgrading the chains so that they are sustainable in the long term.

PART II
RESEARCH METHODOLOGY

2.1. SCOPE OF THE STUDY

This study was conducted from September 2009 to September 2011 in Cambodia and Vietnam. Four provinces and one city in Cambodia were covered, namely Kandal, Kampong Chhnang, Kampong Thom and Siem Reap and Phnom Penh city (Figures 2.1 and 2.2). In Vietnam, Ho Chi Minh and Can Tho cities, as well as 4 provinces of An Giang, Dong Thap and Hau Giang were selected. The study was focused on two value chains: captured and cultured snakeheads in Cambodia, and captured snakeheads in Vietnam.

2.2. METHODS OF DATA COLLECTION

This study collected both secondary and primary data. The secondary data and information is derived from government and other sources to complement primary data collection and observations. The primary data was collected through individual interviews with key stakeholders such as fishers, hatchery/nursery operators, fish farmers, processors, traders, and end fish consumer who involved in the value chains of captured and cultured snakeheads. In addition, some sector managers were also consulted.

In Cambodia, a total of 465 samples were interviewed in Cambodia, including 120 fishers, 75 fish farmers, 75 traders, 21 processors, 161 end fish consumers and local/sector officers. The total samples in Vietnam were 485, consisting of 220 fish farmers, 77 traders, 11 processors, 156 end consumers, and 21 sector managers.

The tools of data collection were based on two steps. First step, the research team focused on the available of the secondary data from relevant institutions and agencies in order to better understand of the real context had been done so far. Second step was based on the data collection at field level with targeted key stakeholders by using semi-structured and structured questionnaire for interview to obtain information.

- Secondary data collection was done using the available information and reports from relevant institutions such as Inland Fisheries Research and Development Institute (IFReDI), Fisheries Administration (FiA), Provincial Fisheries Administration, Mekong River Commission (MRC), WorldFish Center, SUMERNET, and other related agencies.
- Key Informant Person (KIP): Using semi-structured for interviews with KIP were made between the research team members and provincial fisheries administration, local officers at village and district level of selected provinces and;
- Household individual interview: Using structured questionnaire for interview with selected households was conducted by using a set of 5 questionnaires which were designed. Pre-tested was also used before interviewing in each target groups. There were 5 target groups of households in this study such as fishers, fish farmers, traders, processors and end consumers. These target groups of households were selected based on criteria of small, medium and big level.

2.3. METHODS OF DATA ANALYSIS

All data and information collected were stored in the Access software program to secondary data were synthesized. Furthermore, data analyses were conducted by using the two sources of collected data in each of part of the results and discussion (FGD, KIPs, individual interview).

The descriptive analysis was used to describe the secondary data and to present the characteristics of the target groups. Cross-tabulation was made to describe and to compare the data within and between the group households. Comparative analysis was made to compare the mean value between the groups.

The framework for value chain analysis was based on the references from Michael Porter (1985), Making Markets Work Better for the Poor - M4P (2007), and Deutsche Gesellschaft für Technische/Intenational Zusammenarbeit (GTZ or GIZ). The share of product distribution among actors in the value chain diagram was as follows:

- Processed products were converted into raw materials for calculations;
- Amount of output products of an actor was the amount of input products for next actor following the chain;
- Total input products of the first actors were 100% and total output products of the last actors must equal 100%. The amount of inputs and outputs of each actor must be equal;
- The converted products between the actors at the same level were not accounted for in the value chain diagram.

The following indicators are calculated for a cost-benefit distribution of the chain:

- Added value = Selling price – Purchase price including added cost;
- Net added value = Value added – Cost added;
- Total cost of fisher or fish farmer of snakeheads = Variable cost (i.e. fuel, seed, feed and other expenses) + Fixed cost + Added cost;
- Added cost of traders and processors included transportation cost, hiring cost, hired vehicle cost, and preservation cost;
- All indicators were calculated based on the conversion into one kilogram snakehead;
- Total net income of each actor = Net added value * Average yield of products produced or traded in a year.

The descriptive analysis was conducted using the secondary data to present the characteristics of the target groups. Frequency, percentage, mean, standard deviation, and range were used in the comparative analysis. Cross-tabulation was used to compare the major differences in actors between linkages. The benefits and costs of the involved actors were analyzed in order to help to recommend the most appropriate improvements to the value chain of snakehead in the delta region.

Part III
Value Chain of Snakehead Fish in Cambodia

3.1. DESCRIPTION OF CHAIN ACTORS OF SNAKEHEADS

3.1.1 Small-scale fishers of snakeheads

3.1.1.1 Socio-demographic characteristics of fishers

The age of fishers ranged from 19 to 65 years, with an average 44.21 years, mainly between 31 to 60 years (86%), and females covered only about 5% of total samples. The most common educational level of fishers was primary school (53%), only 2% finished secondary school and higher, but 27% were illiterate. The average fishing experience was about 20 years, ranging from 3 to 45 years, males had higher education but similar fishing experiences as females.

Primary occupations of fishers' households in the study areas were fishing, fish culture and rice farming. The higher percentage of households' major occupation was fishing (82%), the rest involved in rice farming (16%) and fish culture (2%). However, those primarily engaged in fish culture and rice farming activities also had fishing as a secondary occupation. The major secondary occupation was rice farming (25%), fishing (19%), petty/small trading or business (17%); fish culture (14%) and daily paid works (9%), etc.

The average household size of sample fishers 6 persons, ranged from 2 to 9 persons, of which the rates of females and males were. These households had 3.4 family labors, ranged from 2 to 9 persons. About 2.3 family labors involved in fishing activities, at least 1 and the maximum was 7, but more males participated in fishing than females, including family and hired labors. Small-scale fishers do fishing at all times of the year with restrictions mainly on the fishing efforts, for example, type of gears and mesh size, and use only family labor, whereas medium and large-scale fishers are permitted to fish only during the open/main season and they use both family and hired labors fishing operations.

3.1.1.2 Fishing grounds

There are many different type of fishing places where fisher households normally go fishing in the study areas, such as Great Lake Tonle Sap, Tonle Sap River, Mekong River, small lakes, inundated forest and canal/stream etc. Amongst these fishing places, the majority of fishing ground was sample households went to fish were Small river/Lake connected to Tonle Sap River, Bassac River, Mekong River (43%), Great Lake Tonle Sap and along Tonle Sap River (49%) and the rest were inundated forest, rice field and canal/stream. Appendix Table 5 shows the percentage of sample households by fishing ground by fishing season in the study area.

3.1.1.3 Major operating costs for fishing activities

Major operating cost in fishing activities were included fuel/oil, food expenditure, hired labor, interest on borrowed money, taxes, and other expenses - cigarette, wines etc. Operating cost varies in accordance with season, clearly defined as open and close season. Generally, in open season, average total operating cost on fishing activities per day per household was USD 23.3 and USD 9.0 in close season. Moreover, fishers spent more money on hired labor and taxes items. An average number of family labors were around 3 persons in each season. If they hired labor it would cost about USD 3 per day per person in the study areas. Fishers had higher expenses in open season because they spent more time for fishing activity compared to closed season. If fishers used only family labors, the input cost would be decreased. This due to there was high cost of hired labors in the study areas as well as in the country.

Borrowing and lending of money are common in the rural areas of Cambodia. However, majority of small-scale fishers (69.4%) had to borrowed money for fishing. Only 30.6% of fishers used their own money for fishing activities. There were 98% of sample fishers received loans private banks, micro-credit/finance NGOs, local money lenders, and fish collectors/traders. However, only (8%) could borrow money from friends/relatives without interests for their fishing operation. Normally, the average loan for each fisher was USD 1,138.6, ranged from USD 20 to 20,000 with a high interest of 5% per month, ranged from 1% to 35%. The common duration for the loans was 10 months, varied from 2 months to 3 years. The purposes of loans were mostly for fishing gears, boat engines, fuels, etc. Besides, the loans could be used for buying rice, medical treatment, schooling of children, inputs and cattle/cows for farming, and also small business.

Several fishing gears were found in the study areas such as gillnet (Mong), seine net (Oun), cast net (Somnanh), Hook and line (Santuch), horizontal cylinder trap (Lorb), bamboo fence (Prourl), and vertical cylinder trap/vertical hanging vase trap (Tom). Amongst of these fishing gears, bamboo fence and trap, gill net, hook and line were commonly used in the study areas. An average of bamboo fence was 29, followed by gillnet (18), horizontal cylinder trap (11), hook and line (6), seine net (6), and cast net (1). Generally, an average cost per unit of seine net was highest (USD 1,369); annual maintenance cost was USD 184.4, with expected life of about 6 year. Followed by bamboo trap was USD 62 per unit, maintenance cost was USD 21 per year with expected life of 3 year. Moreover, boats and machines were costly, USD 435 and USD 380, respectively. Therefore, they need capital to buy some fishing gears suitable to their fishing grounds and equipment as fishing boats and machineries.

3.1.1.4 Production of wild snakehead capture

The fishing calendar of inland fisheries in Cambodia is divided into two seasons: Open (October to May) and Closed (June to September). Generally, during open season consists of peak period and low period of fish caught the same as snakehead species. Based on the results of the study shows that the peak period of wild snakehead was from October to February and low period was March to May during open season.

Overall, an average day per month and number of month for fishing activity was the same during open and closed season. This implies that the fisher sample households in the four selected provinces study areas are living depend on fishing activity and fishing is the main occupation. The result shows that the average fish caught per day was higher in open season (44.6 Kg) and only 8.8 Kg in closed season. Specifically for snakehead, quantity of fish caught was 7.6 Kg in open season and only 0.5 Kg in closed season. Whereas, the average income from fishing activity with all species in open and closed season were USD 39.2, ranged from USD 1.4 to 782.4 and USD 11.8, ranged from USD 0.5 to 87.5, respectively. Specific to snakeheads, in open season was USD 11 and in closed season was USD 4.4. Moreover, the average total sample household income, including fishing and non-fishing activity was USD 46.6 per day with ranged from USD 1.4 to 785 in open season and USD 13.8 with ranged from USD 0.5 to 152 in closed season.

Size of snakeheads caught by the sample fisher households was not different between open and closed season. Size of wild snakeheads was categorized into three types: size 1, size 2, and size 3. The average graded size of fish at size 1 was 0.7 kg/fish, size 2 was 0.4 kg/fish, and size 3 was 0.2 kg/fish. Fish size ranged from 0.2 to 2.0 kg/fish and it was bigger during closed season. About 54% of the sample fishers said that the size of snakeheads was decreased, 39% was unchanged while only 7% said that snakeheads was bigger than before.

Over half of fishers who said that the size of snakeheads decreased because of some reasons such as: (i) numbers of fishers were increasing; (ii) not only size of fish but also quantity of fish also decreased because of illegal fishing; and (iii) lower water level either in rivers or lakes that caused the lack of feed for fish and more difficult for fish to be able to migrate for breeding and grow well; and (iv) growth of wild fish did not simultaneously to the growth of human population or consumption.

Controversially, very few of fisher households said that size of snakeheads would increase because in close season fish was not allowed to be caught, so it could grow well. Moreover, because there was a decrease in illegal fishing like mosquito net, electric fishing gears so that fish could breed and grow well. Higher water level in rivers or lakes compared to that of previous year (2009) and more small fish/juveniles in rivers or lakes than previous years.

3.3.3.5 Marketing and distribution of snakeheads

An average price of snakeheads got by fisher was lower price than wholesaler and retailer price. Selling price of snakeheads for fisher was higher during low period of open season (March to May) (USD 1.8/kg) and closed season (June to September) (USD 1.7/kg), whereas lowest price during open season (October to February) (USD 1.6/kg). This implies that the average price of snakehead was similar between open and closed season. Regarded to trend of fish price, the result show that about 80% of the sample households said that price of all fish species and snakeheads were increased. Majority of fisher households responded that, the reason for increasing price of snakeheads as well as of other fish species due to the decrease of total fish catch as well as fish stock in the natural resources from day to day, population growth (high fish consumption demand) and the high price of fuels/oils.

Overall, the total production of captured snakeheads by sample household was sold to local fish traders (27%), local processors (22%), traders from other provinces (20%), and own sale at the village and local market (24%) and the rest kept for household consumption (7%). During open season, most of snakeheads (65%) was sold to local fish traders/collectors and local processors and other traders from other province or outsider of the village. Whereas, during closed season majority of fish caught (74%) was sold to trader from other provinces, local traders and local processors. Furthermore, around 21.5% of snakeheads was own sales. In addition, there was no direct selling of fresh snakeheads to supermarkets or restaurants. This implies that, the main buyers of capture snakeheads were local people who used to buy or collect fish and distribute to other traders, buyers according to market demands.

3.1.1.6 Advantages, difficulties and solutions of small-scale fishers

Although fishing activity brought fishermen some hardship and risk, it was still a good choice for them. Moreover, fishing was still the main occupation for household heads and as an additional job for household members to support the families. Moreover, it was very important for daily fish and food consumption, which consists of high protein and nutrition food for them. In addition, it is not only food supply but they could earn some money by selling fish to support their families and send their children to school. Beside this, they could also catch wild small fish for culture as well.

In the future, most of fishers (about 67% to 90%) would not change in all factors relating to fishing grounds/areas, fishing gear/equipment, number of labors involved, fishing techniques, time for fishing, fish marketing, changing career are encompassed in the perception of fisher households. The results shows that only about 10% to 33% of them wanted to change and to expand the fishing ground, to increase number of fishing gear/equipment, number of labors, fishing techniques, time to fishing, fish marketing and want to change from fishing to other possible jobs/livelihoods. Overall, most of them satisfied with their careers as fishers. This implies that majority of sample fisher households would not change their habit or career on fishing activities. This may be they inherited or they got this career from their parents or grandparents. They may also have no alternative jobs or livelihood activities in those areas, and also skills for doing other works.

However, there were some difficulties encountered to fishers. One of which was the shortage of fishing grounds for small-scale fishing activity. In some cases, it was very competitive to have places for fishing. Second, it was the decrease of fish catch and wild fish stock in rivers, resulting from illegal and over fishing. Third, it was high cost of inputs, mainly on fuel, food, fishing gears and informal-fee payments. Another thing, it was lack of capital.

To deal with the lack of fishing grounds, some of fishers had to find new places for fishing in spite that it was far from home. Another thing, some fishers changed to culture fish in complement to wild fish which was deficient. Additionally, some fishers had borrowed money from the banks, micro-finance institution or local money lender in the village with high interest rate to buy fishing gears and pay on other inputs.

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3.1.2 Farmers of snakehead fish

3.1.2.1 Socio-demographic characteristics of fish farmers

Among the total sample of 75 snakehead farmers, 65 were in Kandal province and only 10 samples were in Siem Reap province. These were only two provinces where snakehead were cultured was practiced in ponds and cages. An average age of farmers was 41 years, ranged from 20 to 61 years, majority aged from 31 to 40 years old (29.33%) and from 41 to 50 years old (29.33%). This might be the ages for good experiences in fish culture and capital.

About 53.33% of fish farmers finished their study at primary school, whereas only1.33% finished upper secondary school. The common experience in fish farming was 7.58 years and male household heads had more experience in fish culture than those of females. This implies that fishing experience was not necessarily related to their educational level.

An average size of fish farmers’ household was about 5.17 persons, ranged from 2 to 10 persons, of which males were 2.65 persons. The number of family labors involving in fish farming per household was 3.20 persons, ranged from 1 to 8 persons, in which females shared around 50.83% of total number of family labors for fish culture while almost (94.67%) of fish farmers did not hire labors for fish farming.

3.1.2.2 Production of cultured snakeheads

Farm design and culture techniques

Only two types of farming systems of snakeheads - pond and cage farming systems - were found practicing in the study areas. Before being sold out to markets, snakeheads needed to come across a few steps of hatching, nursing and growing. However, fish was cultured only from nursery to grow-out phases; most of the species cultured were hybrid snakeheads, followed by giant snakehead. Generally, for nursery, each fish farmer household could possess around 1 pond or cage (sized 29.36 m^3 for pond and 7.39 m^3 for cage). Average size of areas for fish farming, if compared to the past, remained unchanged until now no matter fish was nursed or grown in a pond or a cage. Average depth of water containing in the pond was 1.52 m and in the cage was 0.80 m. Average number of crop/cycle at which fries of snakeheads could be nursed in pond and cage was the same which was only 1 time per year. Moreover, a crop/cycle of a pond lasted only 48.73 days, while that of a cage lasted up to 72.47 days. Within the above mentioned volume and water depth, a pond could store around 2,850 heads of fish fries and a cage could hold about 5,118.42 heads of fish fries. Nonetheless, in term of growth, pond and cage might be varied from the former to some extent.

In general, average number of ponds or cages available in each fish farmer household was only one (sized nearly 441 m^3 for pond and 20.60 m^3 for cage). Average depth of water either in a pond or a cage was almost the same (about 2 m for pond and 1.86 m for cage). In addition, snakeheads could only be grown 1 time/year no matter it was fed in a pond or a cage. Average number of days per crop/cycle of raising fish in a pond was 240.41 days; while in a cage was 225.30 days. Moreover, with the aforementioned volume and water depth, a pond could hold around 2,093.94 heads (fish) of fingerlings and a cage could bear about 2,715.48 heads (fish) of fingerlings.

Normally, pond and cage were prepared by most of snakehead farmers in May, June, and July for nursery, and in September for growth. For nursery, average period from preparation to stocking was around 2.3 days and water in pond was usually exchanged in every 9 days with rate of water exchange 44.8%/time. Furthermore, for growth, average period from preparation to stocking was about 4.1 days and water in pond was exchanged in every 10.8 days with rate of water exchange 43.3%/time.

In general, fish fries were mostly nursed in June, July and September. It was then applied into a pond in July and September, and a cage in October and December for growing after becoming fingerlings. Average stocking size of fries for being nursed was from 2.07 grams/head (in a pond) to 3.28 grams/head (in a cage). Moreover, average stocking size of fingerlings for being grown was from 31.36 grams/head (in a pond) to 52.12 grams/head (in a cage). Most of the cases, average stocking size of fries and fingerlings (either in a pond or a cage) remained the same since the past till now.

Supplying sources of fries/fingerlings of snakeheads

Supplying sources of fries and fingerlings of snakeheads included fishermen, nursery sites, fish farmers and importation from Vietnam. Nearly all of fish farmers used fries and fingerlings that were imported from Vietnam (95.7% of the household for nursery, and 89.3% of the households for growth). Since average stocking size of fries and fingerlings varied by pond and cage, its average buying price was also different, to some extent. Overall, average buying price of fries was about USD 0.04/head and of fingerlings was USD 0.22/head.

Feed for cultured snakeheads

Feed for fries and fingerlings, generally encompassed fresh water trash fish, marine trash fish, head and bone of P. Catfish, fresh water crab, commercial/pellet feed, and other feed such as corn and soybean. Average quantity of feed for fries per fish farmer household was about 593 Kg/cycle, in which fresh water trash fish highly contributed about 35.73%, followed by marine trash fish and pellet feed, respectively. Furthermore, average quantity of feed for fingerlings per household was about 5,434 Kg/cycle, in which fresh water trash fish still actively involved around 46.43%, followed by marine trash fish and pellet feed, respectively.

Overall, not all feed mentioned above was totally bought. Some feed was naturally found by fish farmer households from river or lake nearby. It included fresh water trash fish and golden apple snails. Majority of feed for fries was fresh water trash fish (79.84%), while the rest was golden apple snails (20.16%). Moreover, the highest percentage of feed for fingerlings was still fresh water trash fish (70.78%), whereas the remaining was golden apple snails (29.22%). Additionally, types and amount of feed used in fish farming had no change at all from the past until now.

Price of feed for fries and fingerlings was not very different. In average, buying price of feed for fries was about USD 0.33/kg, ranged from USD 0.15 to 0.50. Moreover, average buying price of feed for fingerlings was around USD 0.32/Kg, ranged from USD 0.15 to 0.48. Furthermore, price of fish feed, no matter it was natural or man-made, tended to keep on increasing from the past until now and this trend might continue to the future.

Cost of snakehead culture

Production cost of fish farming covered 2 types of costs: variable and fixed cost. Variable cost included preparation and operational cost. In this context, preparation cost was expense on clearing grass and liming. Operational cost encompassed expenses on buying broods, fish feed, hiring laborers, water exchange (for fish farming in ponds), disease and water treatment, transportation and communication. Furthermore, fixed cost focused on construction cost (with depreciation cost), tax, rent of location, repair or maintenance on the equipment and interest expense. Construction cost referred to expenses on buying equipment and digging ponds or making cages. Thus, average variable cost of each snakehead fish farmers per cycle (year) was USD 2,686.35 and average fixed cost was around USD 340.34. Hence, average total cost was about USD 3,026.69/cycle.

Lack of capital seemed to be big problem when more than 50% of fish farmers had to receive some loans from outsiders for practicing fish culture, including money lenders, banks and NGOs. The money lenders at villages played the most important role when providing the loans to most of fish farmers (63.3% – 69.2%). Normally, the average amount of loan for fish nursery was USD 915, ranged from USD 50 to 7,000 in about 2.06 months, with the interest of 3.80% per month. In addition, the average amount of loan for growing-out fish was USD 865.82, ranged from USD 50 to 7,000 in about 6.44 months, with the interest rate of 3.57% per month.

Harvesting of cultured snakeheads

Habitually, most of fish farmers started to catch fingerlings in September (for pond culture) and October (for cage culture). Thus, these two months were the suitable time for fish farmers to collect fingerlings for stocking into ponds or cages. Normally, the fingerlings were graded into three sizes, that is, size 1 of 66.82 g/fish; size 2 of 45.71 g/fish; and size 3 of 30.48 g/fish. The size of fingerlings was generally around 46.19 g/fish, ranged from 20 to 100 g/fish. The average annual production of fingerlings per fish farmer was around 2,442 fish.

On the other hand, the snakeheads was stocked for 5 to 6 months up to the harvest in April at the three sizes, named size 1 of 1.13 kg/fish; size 2 of 0.74 kg/fish; and size 3 of 0.46 kg/fish. Hence, the average size of snakeheads sold for food was 0.78 kg/fish, ranged from 0.33 to 1.50 kg/fish, in which the majority was size 2 (42.62%), followed by size 1 (36.4%) and size 3 (21%). Generally, the average annual production of snakeheads per fish farmer was about 1,800 kg, in which size 2 shared most (40.67%), followed by size 1 (29.67%) and size 3 (29.67%).

Marketing and distribution of cultured snakeheads

It was obvious that fingerlings, after being nursed, were not sold out to markets. Instead, all of them were grown in either a pond or cage, and would be caught for selling when they became mature snakeheads. Frankly, within total quantity of production per cycle, largest number of snakeheads was sold out to local fish traders (38.8%). It was also sold to wholesalers (31%), to traders from other provinces (18.4%) and own sale in markets (8.3%). Moreover, only less of it was kept for household consumption (3.5%). Snakeheads were mostly sold out without any classification.

Price of snakeheads varied in virtue of fish size. Generally, average selling price of size 1 at farm gate was about USD 2.06/Kg; size 2 was USD 1.97/Kg; and size 3 was USD 1.90/Kg. Thus, regardless of its size, average selling price of the fish was USD 1.98/Kg, ranged from USD 1.50 to 2.50. Trend of selling price of snakeheads from the past until now was no time decreased. Hence, it kept on increasing from day to day and could possibly continue augmenting to the future.

3.1.2.5 Advantages, plan, difficulties and solutions in farming snakeheads

Fish culture via nursery and growth out brought many advantages to fish farmers. First of all, broods of snakeheads were cheaper than fingerlings. Therefore, feeding fish by starting from broods (nursery) was more profitable. Second, culturing fish provided not only fish for household consumption but also for sale for income to support the families. Third, farming fish could be a good job for women since it was done at home and/or short distance from hoe. Thus, women could take care their families and also do some activities to earn more income.

Majority of snakeheads farmers would choose hybrid snakeheads (93.3%) for future snakeheads production due to less dependency on seasonality, as well as hybrid snakeheads were easier to feed and grew faster than wild snakeheads. In addition, hybrid snakeheads might have better resistance to infected diseases and farming practices (pond or cage) of hybrid snakeheads in the areas close to the houses (inland or on the river). Concerning with reproduction techniques and farming activities of snakeheads, most of fish farmers did not have any plan to change because of the limitation of capital, mainly related to expansion of farming system. Moreover, the current species, farming activities and application of feed seemed to be good for cultured snakeheads.

However, there were some difficulties faced by fish farmers, especially feed. The feed used for snakeheads farming was mostly trash/low value fish, so most of fish farmers were difficult to find or afford to buy it since it now was scarce and its price was high. Frankly, there was also some man-maid feed (pellet feed) for fish, yet its price was also high and could be hardly affordable for fish farmers. Another problem was the limitation of appropriate technologies of raising fish which resulted in high mortality of fish due to uncontrollably infected diseases was high. In order to cope with the death rate of fish, fish farmers put more efforts on the farming by frequently exchanging water (ponds) and using medicines, both modern and traditional medicine, to cure disease-infected fish, but these did not have much effects. Furthermore, lack of capital was still a problem for most of fish farmers.

3.1.3 Traders of snakehead fish

3.1.3.1 Socio-demographic characteristics of snakehead traders

Gender, Age, Education and Experience of Snakehead Traders

Majority of fish trader household heads were between 41 and 50 years old (33.85%), but only few of fish traders were older than 60 years old (3.08%) while female covered most of the total number of respondents (87.69%). About 44.62% of the respondent households stopped their study at primary school. Fish traders had trading experience between 2 to 31 years, in which the group of illiterate traders had the longest experience with 18.41 years while those who with upper secondary school had the lowest experience (4.33 years). Average number of members of fish traders' households in the study areas was 4.24 persons, ranged from 1 to 9 persons, 2.06 persons engaged in fish trading, ranged from 1 to 6 persons, (0.75 male and 1.31 female). Most of fish traders did not hire labors (86.15%), while the remaining traders hired about 2 labors, of which the rates of male and female were equal.

3.1.3.2 Trading of snakeheads and trend

Normally, fish was traded at landing sites, markets or home, and sometimes was nomadically traded. Most of traders traded fish at local markets (76.92%), while least of them traded fish at homes (4.62%). Fish traders conducted their fish trading activities, mainly snakeheads, about 10.7 months per year, ranged from 2 to 12 months with an average number of trading days was 24.3 days/month, ranged from 3 to 30 days. Average amount of fish (both fresh water and marine fish, including snakeheads) traded was 94.7 kg, of which 93.1 kg was fresh water fish.

Supplying sources of fresh snakeheads and snakehead processed products encompassed fishers, farmers, retailers, middlemen/whole traders, processors and importers. In term of fresh snakeheads, most of giant snakehead was bought from middlemen/whole traders (27.69%) and fishing lot owners (26.08%). Moreover, most of common snakeheads were bought from processors (25.47%) and middlemen/whole traders (21.45%). For snakehead processed products, large amount of salted-dried fish was supplied by middlemen/whole traders (34.09%) and processors (32.58%). Furthermore, fermented fish/paste was mostly supplied by processors (31.75%), retailers (31.75%), and middlemen/whole traders (30.16%).

The quantity, size and price of fresh and processed products of snakeheads were different by time of trade. Generally, snakeheads were abundant from January to February, but scarce from June to July. In addition, snakehead processed products were plentiful from February to March, but shortage from April to September (from April to July for fermented fish/paste and from July to September for salted-dried fish).

Average quantity of fresh snakeheads traded per day per trader was 127.04 kg (55.37 kg for giant snakehead and 71.67 kg for common snakehead) at the size from 0.56 to 1.30 kg/fish. Processed snakehead products were 16.09 kg (11.09 kg for salted-dried snakehead and 5.0 kg for fermented snakehead fish/paste) at the size between 0.53 and 0.62 kg/fish. Buying price of fresh snakeheads was from USD 2.42 to 2.85/kg while the figures for processed products were between USD 3.68 to 7.50/kg. The traders then resold the fish at selling price of fresh snakeheads from USD 2.70 to 3.16/kg, and for processed products from USD 4.33 to 8.75/kg. Additionally, rate of weight loss during the trade was around 3.78% for fresh snakeheads and was between 4.20 to 12.83% for processed products. Regardless of the weight lost and total costs on trading activities, salted-dried snakeheads were the prioritized products for traders to obtain more profit, followed by fermented snakehead fish/paste. In addition, most of fresh and processed products traded were cultured snakeheads.

The quantity of live snakeheads traded has been unchanged, but it has been decreased in the cases of salted-dried wild snakeheads and fermented snakehead fish/paste (both wild and cultured) while the quantity of salted-dried cultured snakeheads has been increased. In addition, the percentage of fresh wild giant snakehead fish, salted-dried wild snakeheads and fermented snakehead fish/paste have been decreased while that for fresh cultured giant snakehead and fresh common snakehead (both wild and cultured) and salted dried culture snakehead remained unchanged. The size of fermented cultured snakehead fish/paste decreased the size of fresh snakeheads, salted-dried snakeheads and fermented wild snakehead fish/paste stood still unchanged. The quality of snakeheads and the convenience as well as the information for trading remained unchanged to most of trader households. However, the price of all types of snakehead products increased while the convenience in trading preserved products become worse.

3.1.3.3 Costs for trading snakeheads and some supports

The sample fish traders in this study included small, medium and large scales. The average size of areas for trading fish at the markets was 3.16 m2 with average cost on construction/rent about USD 744.32 and equipment USD 207.51 for equipment. Average tax for trading fish in the market was USD 80.80 per annum. At the landing sites, average trading areas was approximately 10.55 m2, with USD 1,920.36 on construction cost/rent, USD 751.38 for equipment and USD 195.81 for annual tax. If trading at home, the average area for trading fish was around 60.33 m2 with the cost on construction/rent was USD 125, for equipment was USD 300 without tax paid for fish trade at home. For nomadically fish traders, these figures were 1.20 m2; USD 18.75; USD 40.13; and USD 57.79, respectively. The average variable cost per fish trade was USD 44,449.65/year and the average fixed cost was USD 1,279.59/year. These made the average total cost of fish trader of USD 45,729.24/year; this also implied the need for capital for trading fish.

Due to the lack of capital, most of fish traders had to depend upon loan from banks as well as received some supports from fish suppliers such as buying fish on credit, and intervention from market officers. On the other hand, fish traders also provided some supports to their buyers. For instance, any buyers who bought more fish would be given free charge of fish transportation to their areas. In addition, fish price was discounted whenever fish was bought by their daily customers. Even more, fish could be sold on credit to their customers who could not pay immediately by cash.

3.1.3.4 Difficulties and solutions for trading snakeheads

Majority of fish traders did not plan to change their business since trading fish was their familiar careers with long experience and permanent buyers which brought about income to support the families. Moreover, most of them had permanent buyers also their limitation in capital.

There were some difficulties to which fish traders confronted in the business. Firstly, amount of fish, especially wild fish were not enough for them to buy and supply to markets. Sometimes because fish was seasonal scarce, most of fish traders had to follow the price auctions where the traders who offered higher price would get fish. As a result, fish would be unavoidably sold at higher price and this made fish traders received only little profit. Fluctuation of market price of fish was another issue when the price of fish always changed through the traders. Furthermore, quality degradation, weight loss and high death rate were important issues, especially during the time for loading/transporting fish to markets. This could not be fully controlled by fish traders since their knowledge on fish conservation. In addition, fish traders spent more money for transportation while limitation of capital was still a problem in the business transaction.

In order to handle quality degradation and dead fish, some fish traders used ice to freeze the fish and others processed fish into salted-dried fish, fermented fish, and fish paste. Some traders simply decided to sell these fish out at lower price, even sometimes at lower level of break-even price.

3.1.4 Processors of snakeheads

3.1.4.1 Socio-demographic characteristics of snakehead processors

Gender, age, education and experience of snakehead processors

About 70% of surveyed processors were female, and 35% of them aged from 41 to 50 years (35%) while it was scare to see young processors at the age of 20 to 30 years (10%). Secondary school was observed with 60% of processors who had 13 years of experience in fish processing while the remaining stooped at primary school and had 12 years of experience, in average. Regardless of educational background, female processors had average processing experience of 14.4 years, longer than that of male processors (8.3 years). This implies that females were dominant and had more experience in processing fish than males. Size of households and labors involving in processing snakeheads

Average size of processor households' member was 4.7 persons, ranged from 2 to 12 persons, of whom 2.5 were female, ranged from 1 to 6 persons. Among family labors, only 3.3 persons involved in processing fish, of which 1.9 and 1.8 persons were males and females, respectively. Fish processing required much work and time, so that some processors could not completely do the fish processing work by themselves, and then nearly half of them used hired workers (2.1 persons, varied from 1 to 6 persons, equaling between males and females).

3.1.4.2 Supply of raw snakeheads for processing

Processed products of snakeheads were preserved from wild and cultured fish, and from different types of suppliers. Majority of wild snakeheads was supplied by other fish processors (28.7%), followed by middlemen (25.7%) and wholesalers (24.1%). In the case of cultured snakeheads, the most important source was from Vietnam (30.1%), followed by fish farmers (24.9%). Average distance to buy wild snakeheads was from 7.4 to 8 km with 2.6 to 3.9% of weight loss during transportation/loading while average distance to buy cultured snakeheads was 3.8 to 15 km with weight loss of 3.9 to 5%.

Snakeheads were then processed into the forms of salted-dried and fermented fish/paste. Commonly, processors conducted their snakeheads processing within 4 to 9 months/year. Fresh snakeheads were usually bought around 6 to 40.2 times per month at about 270.8 to 425.7 kg/purchase. Average size of snakeheads bought varied from 0.5 to 1.0 kg/fish with average buying price of USD 1.9 to 2.5/kg. Annually, a processor could processed salted-dried fish about 126.37 times with a cycle of 2 days/time while fermented fish/paste could be processed only 2 times/year with a longer cycle duration of about 90 days/time.

Not all processors processed only snakeheads. Average quantity of fresh fish (all fish species, including Chhdaur and Raws “snakehead”, Ondaeng “walking catfish”, and Chhveat Doung “shortbarbel pangasius”) and ingredients (salt, sugar, soup powder, garlic, and ginger) bought per year by each processor household was 8,876.2 kg. Within raw materials used, fresh snakeheads used for processing consisted of about 5,858.8 kg, accounting for 66% of all raw materials used for fish processing.

3.1.4.3 Cost of processing snakeheads

Processing snakeheads encompassed variable cost/operational cost, and fixed cost. Generally, variable cost covered the expenses on buying fresh snakeheads, ingredient, hiring laborer, transportation, conservation, communication, and utility. On the other hand, fixed cost was the depreciation of construction works and machineries, and the costs maintenance and interest, tax and rent. Construction works here referred to payment on buying materials and building shelves for keeping fish after cleaned, and sun deck and balcony for drying fish. Machineries for processing fish included machine for beheading fish, machine for shaking fish when cleaned, and water pumping machine. Taxes referred to payment for business operation and environment while not many processors had to pay rent for hiring processing place (mainly came from other provinces in order to process fish in a definite time, and would go back to their provinces at the end of processing period).

The average variable cost for processing snakeheads per processor was around USD 9,582.2/year, and the average fixed cost was USD 605.65/year. Thus, the average total cost of each processor was USD 10,187.83/year.

3.1.4.4 Selling of processed snakeheads

There were 2 types of processed products from snakeheads, that is, (i) salted-dried snakeheads (Trey Ngeat), including whole and headless salted-dried fish, and (ii) snakehead fish/paste without bones (Phra hoc), including fermented snakeheads (Mam). Most of processors conducted their processing activities for salted-dried fish (95%), whereas the remaining was for into fermented fish/paste (5%). In addition, another kind of fish products was observed, namely salted fish cheek - made from fish cheek (Thpal Trey).

Yearly, each processor spent around 9.32 months for processing and selling out their salted-dried snakeheads or 12 months for fermented snakehead fish/paste. Annual total production of processed products per processor was approximately 2,388 kg with average conversion ratio of 2.5:1, in which 92.07% was salted-dried snakeheads and 7.93% was fermented snakehead fish/paste. Average amount of salted-dried snakeheads for selling out per time was 27.79 kg at average price of USD 6.01/kg while average amount and selling price of fermented snakehead fish/paste were 0.50 kg/time and USD 4.25/kg, respectively.

Buyers of snakehead processed products were middlemen, wholesalers, retailers (mainly in Phnom Penh), end consumers, and super markets and restaurants. After processed, all of fermented snakehead fish/paste was sold directly to end consumers in markets. However, for salted-dried snakeheads, most of it was sold to retailers in Phnom Penh (22.3%) and end consumers (22.2%). Moreover, only less of it was kept for household consumption (9.9%)

3.1.4.5 Advantages, difficulties and solutions of processing snakeheads

There were many involvements of outside organizations as well as institutions in processing snakeheads such as: financial organizations/banks or loan providers, local authorities, universities/research institutions, market manager, fish suppliers, buyers and/or consumers, and others. In this context, the supports in term of money/loans, processing techniques and information were more common.

Generally, processing snakeheads is a good activity that allows most of processors to earn more profit to support their family and to sustain their business. This type of business was mainly to meet the demand for snakehead products in domestic markets. Moreover, processed snakeheads shared the largest quantity among different processed products of all fish species. Besides being sold out for profit, processed products of snakeheads were also kept for daily consumption. In addition, processing snakeheads could be done in near-home sites, so processors could have time staying at home and earned more profit for the family.

The processors gave their concern on the further development of snakehead industry in term of the decrease in numbers of processors and quantity of processed snakeheads (55%), while 35% said these would be unchanged and 10% considered an increase. Reasons for the decrease were caused by the scare of supply which leads to augmentation of fish price. In addition, selling fish processed products was quite competitive since there were many sellers, and then lower profit. Half of processors responded that they would change their processing activities while half more said they would not. Only few of processors wanted to increase their production if the demand increased. However, processors of snakeheads had their own difficulties. In most of the cases, the price of fresh/live fish was steadily increasing which leaded to the difficulty to obtain raw fish for processing. It was also difficult for processors to have good products when their knowledge and technique in processing and maintaining products was still limited. They also faced difficulties in selling out the products. Some of them still had problems in packaging and loading/transporting of products to markets. Some processors confronted to some troubles regarding to their own health as the results of hard works as well as long time for processing fish and selling the products, they need to hire labors. Furthermore, processors also encountered some other difficulties such as loss weight of fish when becoming processed fish, cheating from buyers, and lack of capital but high interest rate. When problems occurred, much processors had solutions to deal with it, however, not all solutions were effective.

3.1.5 Consumers of snakeheads

3.1.5.1 Socio-demographic characteristics of snakehead consumers

Gender, age and education of snakehead consumers

Most of respondents were female (80.60%), and those aged from 41 to 50 year old covered 30.60% with the rates of married and divorced were 87.31% and 4.48%, respectively. About 47% of respondent had education at primary school. Household size of consumers was around 5.81 persons, ranged from 2 to 11 persons, of which 2.82 were male and 2.99 were female. In addition, the average number of family members in labor age was only 3.68 persons, ranged from 2 to 9 persons, of which 1.83 was male and 1.85 were female.

Economic activities of snakehead consumers
More than half of surveyed consumption households lived in rural areas, and the rest were in urban and sub-urban areas. They relied on rice cultivation, cash crops, animal husbandry, fish captured and culture, trading, paid works as hired labor, and working as offices. Each household engaged in these activities from 4.49 to 12 months per year. The average annual production cost for these activities was around USD 4,030 which brought about a net income of USD 2,155.20 per year.

3.1.5.2 Consumption of snakehead products

The households spent approximately USD 180.37 for their living expenditures, of which about USD 87.56 was for foodstuff. Within the expenses for foodstuff, USD 31.22 was spent on freshwater fish, of which approximately USD 13.67 was paid for snakeheads. In average, freshwater fish was bought about 17.97 times/month and 0.93 kg/time at average price of USD 1.86/kg. In particular, snakeheads were bought around 6 times/month (since number of times snakeheads were bought equaled 33.45% of number of times for purchasing freshwater fish) and 0.90 kg/time at average price of USD 2.54/kg. Fresh water fish as well as snakeheads were more often bought and consumed than other types of meat and marine fish. Moreover, it was bought in larger quantity per time after chicken (1.27 kg/time).

The sample consumers in this study consisted of fishers, fish farmers, non-fishers and non-fish farmers. For fishers' households, the average annual quantity of all fish caught were approximately 5,815.9 kg, of which wild snakeheads contained 330 kg (229 kg of common snakehead and 101 kg of giant snakeheads). On average, size of wild common snakeheads was 0.41 kg/fish and sold at USD 1.79/kg while the figures for wild giant snakeheads were 0.52 kg/fish and USD 1.92/kg, respectively. They kept around 128.2 Kg of wild snakehead for household consumption.

The fish farmers' households harvested an average production of all fish species of 1,830.7 kg/year, of which giant snakeheads covered 1,576.8 kg at the size of 0.58 kg/fish and was sold at USD 2.2/kg. They kept about 11.9 kg of cultured giant snakehead for household consumption, only.

Habitually, live snakeheads were bought by households once for every 8.44 to 12.63 days with average amount of 0.76-1.70 kg/time. Average distance from home to markets to buy live snakeheads was not far, from 1.35 to 1.63 km. Furthermore, snakehead processed products were bought once for every 21 to 32.60 days with the amount of 0.9 kg/time about 1.64-2.11 km from home. The amounts of both live and processed snakeheads were unchanged.

Live and processed snakeheads were supplied from different sources. Regardless of own captured snakeheads, the distributors of live snakeheads were middlemen (20.43%), retailers (19.83%) and wholesalers (18.65%), followed by fishers and fish farmers. However, for preserved snakehead products, consumers mainly bought from retailers (35.45%) and processors (33.12%).

The average size of live giant snakeheads bought from markets was 0.95 kg/fish at the price of USD 2.92/kg which might increase up to USD 3.35/kg when the fish was scarce (in April, May and July). On the other hand, average size of live common snakeheads was 0.49 kg/fish bought at average price of USD 2.31/kg which could augment to USD 2.75/kg in off-season. Moreover, average size of salted-dried snakeheads was 0.40 kg/fish, with average price of USD 6.27/kg. The fermented snakehead fish/paste was about 0.54 kg/fish and bought at the price of USD 3.51/kg.

The size of live snakeheads and processed products were said unchanged. However, the price was recognized to increase overtime. In the consumer's perception, quality of live snakeheads and their products was good and remained the same from the past until now while these products were easy to be

handled and consumed. In addition, information related to supply for and demand of live snakeheads and their products was more available and easy to access by consumers.
Generally, majority of consumers used snakeheads in live or fresh form (72.37%) while the remaining used processed forms (salted-dried, smoked and fermented). In addition, around 64.48% of consumers preferred consuming live/fresh snakeheads to processed products (35.52%).

3.1.5.3 Plan, difficulties and solutions of snakehead consumers

There were some difficulties for consumers in using snakeheads. The first concern was scare of wild fish while consumers preferred using wild snakeheads than cultured snakeheads. Next, it was reported that most of snakeheads, especially wild snakeheads were bought by traders or wholesalers in order to supply to big markets in city where the fish was sold at higher price. Hence, this took away the fish from rural and sub-urban consumers. The price of snakeheads was said increasing everyday and higher in comparison to that of other fish species. Moreover, this trend led to the cheatings in trading snakeheads, especially in weighing fish in the markets despite of increasing price. To deal with the deficiency on quantity and increasing price of snakeheads, most of consumers would changed to buy other fish species, especially small fish or meat such as pork, chicken or eggs that would be cheaper and more available for them, especially the households had low income level. Alternatively, they would also turn to culture fish, including snakeheads, by themselves. In contrast, some consumers would not change their behavior on using snakeheads because snakeheads were delicious (provided more energy and had less bone) and easy to be processed.

3.2. MARKETING CHANNELS AND COST-BENEFITS DISTRIBUTION OF CHAIN ACTORS IN CAMBODIA

3.2.1 Marketing channels of chain actors for snakehead fishers

The marketing channels of wild snakeheads in Cambodia were quite simple because the majority of them were sold only for domestic markets and consumption. The data from analyzing for the Lower Mekong Basin (LMB) of Cambodia was emphasized only on the region, so the caught snakeheads that were transported to other region (Phnom Penh city, and other provinces) were not calculated in the value for final consumption. Currently, the value chain for caught snakeheads in the LMB of Cambodia was focused mainly on eleven marketing channels:

Channel 1: Fishers -> Retailers -> Consumers
Channel 2: Fishers -> Retailers -> Restaurant -> Consumers
Channel 3: Fishers -> Wholesalers -> Retailers -> Consumers
Channel 4: Fishers -> Wholesalers -> Retailers -> Restaurant -> Consumers
Channel 5: Fishers -> Wholesalers-> Processors -> Retailers -> Consumers
Channel 6: Fishers -> Wholesalers -> Processors -> Retailers -> Restaurant -> Consumers
Channel 7: Fishers -> Wholesalers -> Processors -> Consumers
Channel 8: Fishers -> Wholesalers -> Processors -> Restaurant -> Consumers
Channel 9: Fishers -> Wholesalers -> Processors -> Phnom Penh city
Channel 10: Fishers -> Wholesalers -> Wholesalers in Phnom Penh city
Channel 11: Fishers -> Wholesalers -> Restaurant -> Consumers

Furthermore, the cost-benefit analysis for the value chain of wild snakeheads was emphasized on two main channels, including channel 3 (consumption in the LMB of Cambodia) and channel 10 (consumption in Phnom Penh city). In addition, channel 5 was also analyzed to examine the cost-benefit for when processors were factored in. Remarkably, all types of snakehead products in channel 3, 5 and 10 were converted into raw materials or fresh fish for the economic analysis.

Channel 3: The production cost for fishers for 1 kg of snakehead in term of raw materials was USD 0.57/Kg, with a selling price for the collectors of about USD 1.62/Kg. The net added value (NAV) was USD 1.05/Kg (50.24% of net added value of the chain). Retailers bought snakeheads from the wholesalers at a price of USD 2.11/Kg. The net added value made up USD 0.47/Kg and accounted for 22.49% of total net value added for the chain. The retailers sold fish to consumers at a price of USD 2.93/Kg with a NAV of USD 0.57/Kg, which made up 27.27% of total NAV of the whole chain three.

Channel 5: The added costs and net added value for this channel were converted for one kg of raw material or fresh snakehead. The dried and fermented snakeheads were sold at USD 2.65/Kg and the profit made was USD 0.39/Kg (about 18.1% of net added value of the chain). NAV of channel five was higher than that of channel three (USD 2.16/Kg compared to USD 2.09/Kg) because of a higher net value added of the processor and retailers.

Channel 10: The local wholesalers provided a large amount of snakeheads (made up 22.1% of total raw snakehead in the LMB) to the wholesalers in Phnom Penh city. The NAV of this channel was USD 1.52/Kg and the profits for farmers (accounted for 69.08% of net value added) were higher than that of the wholesalers (30.92%).

3.2.2 Cost-Benefits distribution of chain actors of captured snakeheads

The profit distribution for the chain actors, however, was differed when the annual profit of each actor was used. The percentages of net added value/agent/year for wholesalers of channel 3, 5 and 10 were 90.54%; 88.72%; and 96.83%, respectively. The fishers received the highest profit per kilogram but they caught the smallest amount of fish earning them less profit than the other groups.

Most snakehead products were sold in domestic markets. The amount of caught snakeheads decreased in the dry season and close season, causing increase in the price of snakeheads. Furthermore, most fishers said during this season they had more problems such as fishing sites far from home, spend much money on fuel oil, catching small amount, and overgrowth of fishers resulting in negative profit of their career.

3.2.3 Marketing channels of chain actors for cultured snakeheads

The marketing channels of cultured snakehead in Cambodia were quite similar to that of wild snakeheads because the majority of them were sold only for domestic consumption. Therefore, the value chain for cultured snakeheads in the Lower Mekong Basin of Cambodia is concentrated mainly on eleven marketing channels:

Channel 1: Farmers -> Retailers -> Consumers
Channel 2: Farmers -> Retailers -> Restaurant -> Consumers
Channel 3: Farmers -> Wholesalers -> Retailers -> Consumers
Channel 4: Farmers -> Wholesalers -> Retailers -> Restaurant -> Consumers
Channel 5: Farmers -> Wholesalers-> Processors -> Retailers -> Consumers
Channel 6: Farmers -> Wholesalers -> Processors -> Retailers -> Restaurant -> Consumers
Channel 7: Farmers -> Wholesalers -> Processors -> Consumers
Channel 8: Farmers -> Wholesalers -> Processors -> Restaurant -> Consumers
Channel 9: Farmers -> Wholesalers -> Processors -> Phnom Penh city
Channel 10: Farmers -> Wholesalers -> Wholesalers in Phnom Penh city
Channel 11: Farmers -> Wholesalers -> Restaurant -> Consumers

For cultured snakeheads, the cost-benefit analysis of value chain was focused on two main channels, including channel 3 (consumption in the LMB of Cambodia) and channel 10 (consumption in Phnom Penh city). In addition, channel 5 was also analyzed to examine the cost-benefit for when processors were factored in. All types of snakehead products in channel 3, 5 and 10 were converted into raw or fresh fish for the economic analysis.

Channel 3: The production cost for farmers for 1 kilogram of snakeheads in term of raw materials was USD 1.56/Kg, with a selling price for the collectors of about USD 1.98/Kg. The net added value (NAV) was USD 0.42/Kg (38.06% of net added value of the chain). Retailers bought snakeheads from the wholesalers at a price of USD 2.11/Kg. The net added value made up USD 0.11/Kg and accounted for 10% of total net value added for the chain. The retailers sold fish to consumers at a price of USD 2.93/Kg with a NAV of USD 0.57/Kg, which made up 51.94% of total NAV of the whole chain three.

Channel 5: The added costs and net added value for this channel were converted for one kg of raw material or fresh snakeheads. The salted-dried and fermented snakeheads were sold at USD 2.65/Kg and the profit made was USD 0.39/Kg (about 33.33% of net added value of the chain). NAV of channel five was higher than that of channel three (USD 1.17/Kg compared to USD 1.10/Kg) because of a higher net value added of the processor and retailers.

Channel 9: The local wholesalers provided a large amount of snakeheads (made up 28.7% of total raw snakeheads in the LMB of Cambodia) to the wholesalers in Phnom Penh city. The NAV of this channel was only USD 0.53/Kg and the profits for farmers (accounted for 79.20% of net value added) were higher than that of the wholesalers (20.80%).

3.2.4 Cost-Benefits distribution of chain actors for cultured snakeheads

The profit distribution for each chain actor was differed when the annual profit of each actor was used. The percentages of net added value/agent/year for wholesalers of channel 3, 5 and 10 were 72.53%; 67.77%; and 93.36%, respectively. Actually, the retailers received the highest profit per kilogram but they traded the smallest amount of fish earning them less profit than the other groups.

Conventionally, most cultured snakehead products in Cambodia are sold in domestic markets. During flooding season, Cambodian fish farmers abandoned their fish culture (fish culture in pond) or kept their fish until dry season (fish culture in cage) because of decreasing in the price of snakeheads resulting in negative profits for many farmers. In the dry season, the price of snakeheads increases because of less wild fish caught. However, the farmers said that they had more problems with fish diseases and nursing techniques on cultured snakeheads in this season. Therefore, the price of snakeheads was unstable, reflecting an uncertain development in this industry.

3.3. MAJOR SUGGESTIONS FOR UPGRADING THE VALUE CHAIN OF SNAKEHEADS IN CAMBODIA

Major solutions/suggestions for upgrading the value chain of snakeheads in the LMB of Cambodia toward sustainable development were proposed as follows:

1. To well manage wild snakehead stock and other inland aquatic resources, specifically to put high pressure and prohibit on all illegal fishing, over fishing, or any activities that harm these resources in order to make sure that it is sustainable for people consumption. This cannot be effectively done unless the involvement of local people/community, local authorities and government, incorporated with NGOs and functional organizations.

2. To augment and to adopt appropriate technologies for farming snakeheads, including fish bloodstocks and feed, especially pellet feed for replacing the trash/low value fish which has been considered as the main food for people, particularly for the poor, to reduce rate of fish death and improve quality of fish as much as possible. By promoting snakehead fish farming, it is hopefully expected that cultured snakeheads can firstly be used to sufficiently complement or replace wild

snakeheads, and secondly to reduce the price of fish to fit people's household income to guarantee the supply of fish for the poor, particularly snakeheads.

3. To have good management of fish traders in order to make the information of fish price more clearly and broadly accessible to all chain actors that helps to prevent price fluctuation. It is vital to ensure that each chain actor can possible obtain the same benefit to sustain value chain as well as snakehead traders.

4. To improve the management of fish quality by introducing more proper conservative technologies, mainly for loading/transporting the fish products to markets in fresh forms, to cut down rate of fish death and weight lost during business transaction. Moreover, to provide more appropriate processing techniques to sustain the processing activities and to increase opportunities for domestic and export markets for both fresh and processed products.

5. To provide more opportunities for the establishment of many financial organizations which tend to offer more loans with lower interest rates.

6. To limit or to restrict the unnecessary and informal-fee payment which usually occur to all chain actors during their business transaction.

Part IV
Value Chain of Snakehead Fish in Vietnam

4.1. DESCRIPTION OF CHAIN ACTORS OF SNAKEHEADS

4.1.1. Reproduction and nursery of snakehead seed

Depletion of natural aquatic resources and rapid development of farming activities of snakeheads have pushed the breeding techniques to be more active in supplying fish seed. The natural breeding method was applied by all of the hatcheries of snakeheads. This is consistent with the study of Duong Nhut Long and Tran Thanh Hieu (2010) showing that natural reproduction is more effective than semi-natural stimulation and artificial methods. The average area of hatcheries was 103.3 m^2, with 30 days for each production cycle when fish get to a size of 1,000-1,200 fingerling/kg. The average amount of fish per reproduction cycle or batches was about 143,900 fingerling at a size of 1,100 fish/kg with an average price of USD 0.01/fish. These fish were mainly kept for nursing and growing out (69.4%). The total production cost for a giant snakeheads (*Channa micropeltes)* hatchery was USD 8,337.14, which is much higher than that for common snakeheads (*Channa striata*) (USD 337.14 to 554.29). The total variable costs accounted for 97.0% of the total production cost. However, the reproduction costs of hatching common snakeheads was lower (USD 0.005/fry) than that of giant snakeheads (USD 0.012/fry). The production costs, income, and profits of common snakehead hatcheries were lower than those of giant snakehead but the rate of return was higher. This shows that the small-scale reproduction of snakeheads is more efficient in economic terms.

The average area of nursery site was 293.7 m^2 with the time per cycle of nursing ranged from 70-90 days and then fishes were harvested for selling out or kept for their own culture activities. The average nursing density was 1,000 fries/m^2 with a size of 750-1,500 fries/kg at a price of USD 0.013. The average survival rate was 63.4% and the yield was 38,800 fries per batch with sizes of 500-1,500 kg/unit. The total nursing costs was USD 1,788.57 per cycle, in which the fixed costs accounted for 1.7%, including the depreciation of machinery and construction (56.9% and 43,1% respectively). The total variable costs were mainly used for buying feed (53.8%), fingerlings (28.1%), and drugs (11.3%). The average gross income was USD 2,520 per cycle making a profit of USD 725.71. The unit production cost was USD 0.048/fingerling with the price of USD 0.069. In the nursery stage, this included 12% of households that had negative profits because of higher production costs.

4.1.2. Growing out of snakeheads

The average density of all models was 114 fingerling/m^3, in which hapas and cages in the rivers had the highest density (190 fingerling/m^3). The density of fish in earth ponds was the lowest (66 fingerling/m^2), which was almost equivalent to the density of catfish stocked in ponds (67 fingerling/m^2) (Nguyen Van Ngo, 2009). The size of the fingerlings was from 350-785 individuals/kg, with a price of USD 0.021-0.063/individual.

Freshwater trash fish and marine trash fish were two main sources of feed for snakehead (50.2% and 38.9% of total amount feed respectively). Some farmers bought by-products of tra catfish and silver carp from processing companies as the feed for their snakeheads. Several companies produced commercial feed and there were a small number of households (3.0%) that used the pelted feed priced at USD 0.983/kg. The feed conversion ratio (FCR) of live feed was from 3.9 to 4.3 and for palette feed it was from 1.2 to 1.4.

At the harvest, the survival rate of snakeheads was quite low (from 48.7 to 56.1%) due to current techniques for culturing snakeheads and also they are carnivorous fish. These techniques could be improved in order to increase survival rate and reduce risk. Snakehead cultured in ponds had a yield of 257.8 tons/ha/ crop. This was lower than the catfish yield (351.8 tons /ha /cases) in Dong Thap in 2008 (Nguyen Van Ngo, 2009) but higher than the average fish yield of the whole MKD (157 tons/ha/year) (MARD, 2008). Therefore, it is possible to achieve equal performance in intensive farming and production of snakeheads in ponds as intensive catfish farming within a small area. And then snakeheads can be considered as a species that helps to promote intensive fish farming and to diversify fish species in the Mekong Delta. The average price of snakehead was USD 1.65/kg, depending on season and species as well as on traders in what year. The results showed that the price of cultured snakehead in Hau Giang province was lower than that of snakeheads cultured in other provinces because there was less dependence on fish traders.

The capital was an important input for cultured snakehead. The average total production cost was about USD 15,697.14/crop, in which fixed costs accounted for 1.6%, mainly as a result of depreciation of construction (83.7%). The variable costs, listed from greatest to least include: feed (88.1%); fingerlings (4.8%); drugs (2.6%); interest of loans (2.2%). The average unit cost was USD 1.7/kg, with a selling price of USD 1.65/kg. The successful level in farming snakeheads was still low while 52.3% of the farms surveyed had negative profits. However, farmers would have obtained positive profits of USD 0.229/kg if the cost of their own captured trash fish and the rate of negative profits of the farmers decreased to 35.8%.

4.1.3 Traders/middlemen of snakeheads

Traders of snakeheads including wholesalers and retailers, which sell fresh, dried, and salted fish. The trading area for wholesalers was large (154.9 m^2) in comparison with that of the retailers (3.6 to 4.9 m^2). The amount of fresh snakehead purchased by wholesalers averaged to approximately 2.2 tons/day, and for the retailers it averaged to 17kg/day. The dried and salted snakeheads sold by retailers were averaged to 4.4 and 6.3 kg/day, respectively. The wholesalers usually bought fresh fish with a size of 530 grams/fish at a price of about USD 1.62/kg and then they sold it at the price of USD 1.77/kg. The size of fresh snakehead sold in the markets averaged about 525 grams/fish, with a buying price (USD 2.54/kg) and a selling price of about USD 2.83/kg. The size of dried and salted snakeheads ranged from 216 to 336 grams/fish with the buying and selling prices much higher than fresh ones (USD 7.83 and USD 9.14 for dried and salted snakeheads, respectively). The fermented snakeheads were bought at USD 3.6/kg and then resold at USD 5.03/kg on average.

The added cost to wholesalers was approximately USD 0.051/kg and for the retailers it was from USD 0.08 to 0.46/kg on average, in which the variable costs largely varied between the wholesalers and retailers (73.8% to 96.0%). These helped to bring about the added income of USD 0.149/kg and made an average profit of USD 0.097/kg for the wholesalers while the profit of retailers was from USD 0.206 to 1.06/kg.

4.1.4 Processors of snakehead products

Most of the total production of snakeheads was for domestic markets because this species is a popular food among fish products. Snakeheads are often consumed in different types such as, fresh, dried, fermented, etc.

For the export of snakehead fish: Le Xuan Sinh & Do Minh Chung (2010) reported that about 0.6-1.0% of the total production of snakehead was sold to Cambodia in fresh form. There are several processors in the Mekong Delta exporting snakehead products to the U.S market, South Korea, and the EU, mainly in the form of frozen fish, dried, and salted products (Association Vietfish Fair, 2010). The products included frozen fillets, whole cleaned, headless, cut into pieces, and value added snakehead products. The exported filleted products usually were from giant snakehead because of their larger size, higher proportion of fish fillets. The limitation of traditionally imported markets was a constraint that should be studied more. Dried snakehead originated from Ca Mau province and it was exported to Australia at a price of USD15/kg by Ocean Food joint-stock company (Ca Mau). There are two dried products of snakehead including dried-spicy and dried non-spicy. To process 1 kg of dried-spicy snakehead about 4-5 kg of fresh fish was required. However, the export of snakehead products was still very limited and occurs approximately 2-3 time per year and 40 tons per time.

In the case of processing fish for domestic consumption: the raw fish used for materials were mainly from smaller sized snakehead that were much cheaper and called "drift." The buying price of raw fish for processing dried snakehead ranged from USD 1.71 to 1.83/kg. There were two dry snakehead products traded in the local or domestic markets. They were in boneless form and whole fish form. To get 1 kg of dry snakeheads 3 kg of whole snakehead or 4 kg of boneless snakehead were needed. The average amount of raw snakeheads purchased for processing was 8.2 tons/processor/year and the production of dried snakeheads weighed about 2.0 tons/processor/year. Dry processing costs and selling price were slightly different between two forms. The processing cost was USD 1.86/kg for dried whole fish and then it was resold at price of about USD 2.3/kg of raw materials. The processing costs and selling prices for the boneless snakehead were USD 2.03/kg and USD 2.47/kg, respectively. However, profit per kg of raw materials showed no difference between the two types of dry products (USD 0.45/kg).

For fermenting snakeheads: the quality of raw fish was very important so the input materials were selected very carefully. The fermented wild caught snakehead were better quality than cultured snakehead (71.4% of processors). Fermented products from snakehead were very diversified and included: (i) fermented whole fish (100% of processors accounted for 45.0% of the total amount of fermented fish), (ii) fermented boneless (71.4% and 27.2% total amount of wild and cultured snakeheads), and (iii) fermented giant snakeheads (28.6% and 20.1% total amount of snakeheads) and (iv) cut-pieces fermented snakeheads (14.3% and 7.7% total amount of snakeheads). The total raw materials of snakehead purchased for fermenting was 9.0 tons per processors per year and it sold for nearly 5.0 tones per processor per year. To get 1 kg of fermented fish, it took approximately 1.8 kg of fresh fish, and for the boneless form the processors needed the highest ratio (2.1 kg of raw materials to produce 1 kg of final products). Some of other remaining types of processed snakehead acquired similar results (1.5 to 1.6 kg of raw material to produce 1 kg of final products. The production cost was USD 2.3, in which the cut fermented fish (mixed with papaya) had the highest cost (USD 2.32/kg) and the lowest cost was cut paste form (USD 1.55/kg). However, the highest profit achieved from the fermented whole fish was USD 0.897/kg of raw fish. The cut paste form incurred the lowest production costs, but received higher profits than other forms (USD 0.74/kg).

In this study consumer groups in urban and rural areas were broken down into subgroups based on their administrative locations or distance from the central town of the province or district. The income of the household consumers in rural areas were mainly from rice farming (45.0% of households) and small trading (36.7%) while the main source of income of urban consumers were from different kinds of trading activities (51.1% of households), salary from employment in the labor field (31.9%), or civil service field (29.8%). Because of the higher standards of living in an urban area compared to a rural area, the living expenditures for urban consumers was higher than that of rural ones (USD 205.71 compared to USD 114.29/month). This included expenses for food (accounted for 61.0%). Freshwater fish were purchased the most frequently (14 times/month), while poultry and beef were much more infrequent (3 times/month). Snakehead, especially the common one was a favorite food in the Mekong Delta region (83.8% of households), followed by anabas or climbing perch (72.1%), and then marine fish (33.1%). This seemed to be unchanged after 13 years from the surveys conducted by Sinh et al (1998).

4.1.5 End consumers of snakehead products

In this study consumer groups in urban and rural areas were broken down into subgroups based on their administrative locations or distance from the central town of the province or district. Rural households had larger size than urban ones (5-6 persons compared to 4-5 persons). The income of the household consumers in rural areas were mainly from rice farming (45.0% of households) and small trading (36.7%) while the main source of income of urban consumers were from different kinds of trading activities (51.1% of households), salary from employment in the labor field (31.9%), or civil service field (29.8%). Because of the higher standards of living in urban areas compared to rural area, the living expenditures for urban consumers was higher than that of rural ones (USD 205.71/month compared to USD 114.29/month). This included expenses for food (accounted for 61.0%).

Freshwater fish were purchased the most frequently (14 times/month), while poultry and beef were much more infrequent (3 times/month). A larger amount of products per purchase seemed to be made by urban consumers due to less opportunity to have self-supplied sources. Diseases on livestock and poultry as well as high price of beef had strong impacts on the consumers' behavior.

Snakehead, especially the common one was a favorite food in the Mekong Delta region (83.8% of households), followed by anabas or climbing perch (72.1%), and then marine fish (33.1%). This seemed to be unchanged after 13 years from the surveys conducted by Sinh et al (1998). The main reasons consist of: these fish were delicious (59.5%), reasonable price (29.0%) and easy to be processed. Most of the households used food fish in terms of fresh type (98.6%) while not many of them bought dried, fermented or canned fish.

Rural households mainly bought snakehead fish products from retailers in the local areas and markets (90.5%) while the main supply of fish for urban households were also from retailers in the nearest markets (89,7%). Fresh fish were bought for household consumption about every 7 days (±12) with 0.7 kg/purchase (±0.5) at size of 0.5 kg/fish (±0.2) and USD 2.48/kg (±0.51). Fish consumers gave their consideration mainly to the quality of fish products when buying dried fish (8.6/10 points), fermented fish (8.7/10 points) and fresh fish (8.0/10 points). The next priorities were price and sellers' behavior (both 7.7/10 points), species, that is, common snakeheads were better (7.0/10 points). However, identification of captured or cultured fish was difficult to the consumers even though they preferred to have captured/wild fish. In addition, the convenience in processing of processed fish for meals was also an important factor (8.5/10 points).

4.2. MARKETING CHANNELS AND COST-BENEFITS DISTRIBUTION OF CHAIN ACTORS

The marketing channels of snakehead were quite simple because they were used mainly for domestic consumption. The data for the Mekong Delta (MKD) was the only region analyzed so the snakehead that was transported to other regions (HCM city, and the provinces in the south east part of the country) were not calculated in the value for final consumption. Currently, the value chain for cultured snakehead in the MKD is concentrated in ten marketing channels:

Channel 1: Farmers -> Retailers -> Consumers

Channel 2: Farmers -> Retailers -> Restaurant -> Consumers

Channel 3: Farmers -> Wholesalers -> Retailers -> Consumers

Channel 4: Farmers -> Wholesalers -> Retailers -> Restaurant -> Consumers

Channel 5: Farmers -> Wholesalers-> Processors -> Retailers -> Consumers

Channel 6: Farmers -> Wholesalers -> Processors -> Retailers -> Restaurant -> Consumers

Channel 7: Farmers -> Wholesalers -> Processors -> Consumers

Channel 8: Farmers -> Wholesalers -> Processors -> HCM city and export

Channel 9: Farmers -> Wholesalers -> Wholesalers in HCM city

Channel 10: Farmers -> Wholesalers -> Restaurant -> Consumers

The focus of the cost-benefit analysis for the snakehead value chain was conducted for two main channels. They were channel 3 (consumption in the MKD) and channel 9 (consumption in HCM city). In addition, channel 5 was also analyzed to examine the cost-benefit for when processors were factored in. All types of snakehead products were converted into raw materials or fresh fish for the economic analysis.

Channel 3: The production cost for farmers for 1 kg of snakehead in term of raw materials was USD 1.394/kg, with a selling price for the collectors of about USD 1.65 per kg. The net added value (NAV) was USD 0.251 per kg (28.8% of net added value of the chain). Retailers bought snakeheads from the wholesalers at a price of USD 1.77/kg. The net added value made up USD 0.069/kg and accounted for 7.8% of total net value added for the chain. The retailers sold fish to consumers at a price of USD 2.4/kg with a NAV of USD 0.554/kg, which made up 63.4% of total NAV of the whole chain three.

Channel 5: The added costs and net added value for this channel were converted for one kg of raw snakeheads. The dry and fermented snakeheads were sold at USD 2.06 per kg and the profit made was USD 0.074/kg (about 9.0% of net added value of the chain). NAV of channel three was higher than that of channel five (USD 0.87/kg compared to USD 0.82/kg) because of a higher added costs of the processing agent.

Channel 9: The local wholesalers provided a large amount of snakehead (made up 57.3% of total raw snakeheads in the MKD) to the wholesalers in HCM city. The NAV of this channel was only USD 0.32/kg and the profits for farmers (accounted for 78.6% of net value added) were higher than that of the wholesalers (21.4%).

The profit distribution for the chain actors, however, was differed when the annual profit of each actor was used for calculation. The percentages of net added value/agent/year for wholesalers of channel 3, 5 and 9 were 87.9%; 91.1%; and 93.4% respectively. The retailers received the highest profit per kg but they purchased the smallest amount of fish earning them less profit than the other groups.

Most snakehead products are sold in domestic markets. These fish are abundant in the flooding season, causing a decrease in the price of snakehead resulting in negative profits for many farmers. In the dry season, the price of snakehead increases because of fewer wild fish caught. However, the farmers said that they had more problems with fish diseases on cultured snakehead in this season. Therefore, the price of snakehead was unstable, reflecting an uncertain development in this industry.

4.3. MAJOR SUGGESTION FOR UPGRADING THE VALUE CHAIN OF SNAKEHEADS IN VIETNAM

Although the LMB of Vietnam provides a large amount of snakehead for domestic consumption and some for export, the future development of this industry is unclear. Cultured snakehead farmers were mainly used in live feed or trash fish, and family labor to overexploit these freshwater fisheries resources. Most of provinces in the delta do not encourage the culture of these fish but neither creat the prohibition on them. This has lead to a spontaneous development of snakehead systems with very little if any planning leading to major difficulties in their management. The future development of snakehead culture is difficult to be predicted because snakeheads are cultured with high density and strongly depend on the feed. However, better development of snakehead culture requires an improvement in both the supply and the use of pellet feed with more care given to the water management. Currently, there are several types of pellet feed for snakeheads on the markets, but these types of feed are considered expensive and poor in quality.

The application of SWOT analysis that identifies strengths, weaknesses, threats, and opportunities was conducted. This helped to produce major solutions for upgrading the value chain of snakeheads in the LMB of Vietnam towards sustainable development in the future were proposed as follows:

1. To develop intensive farming systems of snakeheads using pellet feed with regards given to environmental issues. The use of pellet feed can help reduce water pollution in culture areas compared to the use of trash fish, and also reduce pressure on wild fish stock. A better production

and application of pellet feed also helps reduce production costs as lower FCR, lower costs for labors and transportation.

2. To establish clubs or cooperatives of each or several groups of chain actors within the snakehead industry and to develop the linkages/cooperation within groups and among groups of chain actors for better production and marketing of snakeheads.
3. To have a better management of fish traders in order to stabilize the price of fish or to limit its price fluctuation. It is important to ensure the floor price is an equal distribution of the costs and profits among the chain actors.
4. To consider the policies that support the processing and exporting companies to expand markets; to further development of cultured snakehead industry involved in the export of aquatic products because snakehead production is currently only adequate for domestic consumption. Therefore, export-oriented policies are necessary to increase the production of snakehead as well as for the reduction of risks to the chain actors.
5. To prepare the planning for snakehead culture areas in order to create a stable supply of raw materials for export. Currently, there is high potential for snakehead culture in the delta as there are suitable water bodies for a large culture area and production.
6. To study more on the trade of low value fish and also snakeheads between Cambodia and Vietnam for a better management of wild fish resources and an improvement in the marketing of snakehead products between the two countries.

PART V
CONCLUSIONS

5.1. VALUE CHAIN OF SNAKEHEADS IN CAMBODIA

Marketing channels of snakeheads in Cambodia were very simple since snakeheads were sold only for domestic consumption. Market channels of snakeheads were mainly derived from two types of suppliers, that is, fishers (wild/capture snakeheads) and fish farmers (cultured snakeheads). In addition, some of cultured snakeheads were imported from Vietnam, about 400 tones per year (1% of their annual total production). The important chain actors involving in the value chain of snakeheads in Cambodia were fishers, fish farmers, wholesalers, retailers, and processors. The value chain of wild snakeheads was focused on 11 marketing channels with two most important ones were: (1) "Fishers -> Wholesalers -> Retailers -> Consumers"; and (2) "Fishers -> Wholesalers -> Wholesalers in Phnom Penh city". The value chain of cultured snakeheads was also concentrated on 11 marketing channels, of which two most important channels were: "Fish Farmers -> Wholesalers -> Retailers -> Consumers" and "Fish Farmers -> Wholesalers -> Wholesalers in Phnom Penh city".

Benefit distribution of the chain actors in the value chain of wild and cultured snakeheads was unequal. For that in value chain of wild snakeheads, the highest amount was going to collectors/wholesalers. The main disadvantages of snakehead fishers were: 1) small amount of caught snakeheads could not meet the consumption demand in domestic markets; 2) snakehead fishers could not completely rely only on fishing since wild snakeheads have become scarce.

For benefit distribution of the chain actors in value chain of cultured snakeheads, the highest profit was going to collectors/wholesalers. The main disadvantages of snakehead farming were: 1) the widespread and continuation of snakehead culture using low-valued fish/trash fish as main source of feed which led to the depletion of low-valued fish/trash fish stock, increase price of low value fish, and lack of low value fish for human consumption, especially for the poor; 2) snakehead culture has been banned since 2005; 3) consumers' acceptation of cultured snakeheads was still limited; and 4) most snakeheads fish was preferably consumed in fresh form. In addition, the main disadvantages of all types of sample households were: 1) lack of capital; 2) shortage of skill/technology in the business; and 3) lack of experience in the business.

In order to sustainably develop the value chain of snakeheads in the Lower Mekong Basin of Cambodia, an appropriate plan should be taken into action with collaboration of local community, local authority, government, NGOs, and functional organizations on well manage wild snakehead stock and other aquatic resources, and simultaneously prohibited all illegal fishing and over fishing on the resources. In addition, proper technology of breeding and raising snakeheads, introducing/encouraging the use and producing of pellet feed, and processing snakeheads should be adopted and promoted. Possibility of obtaining profits must be ensured for all snakehead chain actors by accessing to price setting and market information and conservative techniques of snakeheads and snakehead products during business transaction. Moreover, snakeheads and processed products from snakeheads should be promoted to high quality-oriented products by fisheries policies to increase opportunities for domestic and export markets.

5.2.VALUE CHAIN OF SNAKEHEADS IN VIETNAM

There were five major groups of actors involved in the value chain of cultured snakehead in the MKD: farmers, wholesalers, processors, and retailers, and two supportive groups including the market managers and sector managers. The value chain of snakehead in the MKD consists of ten marketing channels. Two most important channels were: (1) "Farmers -> Collectors -> Retailers -> Consumers in the Mekong Delta", and (2) "Farmers -> Collectors -> Wholesalers in Ho Chi Minh city".

The profit distribution of actors was unequal, with the highest amount going to the collectors. The main disadvantages of snakehead farming were: (1) common use of feed, mainly live feed; (2) snakehead culture had been spontaneously spread without planning leading to difficulties in managing it; and (3) snakehead were a favorite product and mainly consumed in domestic markets.

In order to develop the value chain of snakehead for the long-term in the MKD, an appropriate plan must be prepared in association with better management of capture fisheries and the protection of natural aquatic resources. It would also be beneficial to offer more technical trainings and to improve the supply and the use of pellet feeds. Furthermore, improvement in the organization and management of production of products, including policy to supporting the processors for further development of markets, especially export markets would greatly improve this value chain.

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Figure 1: Location of the Lower Mekong Basin

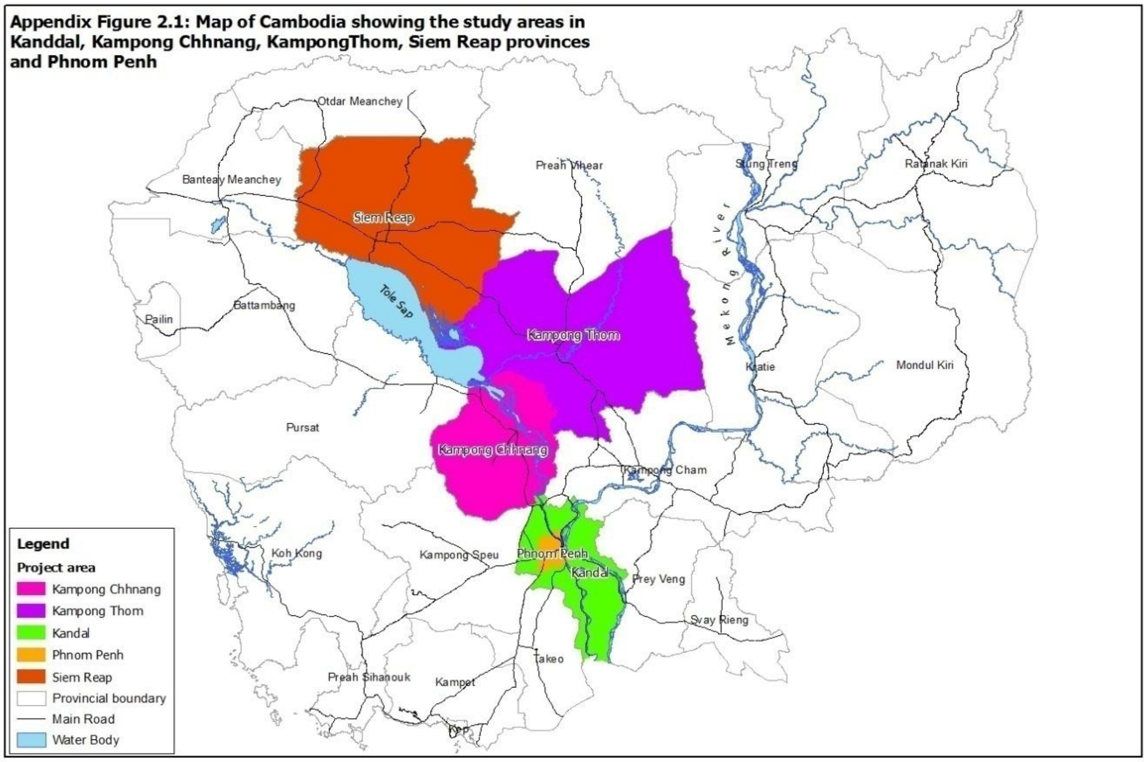

Figure 2: Selected provinces for study in Cambodia

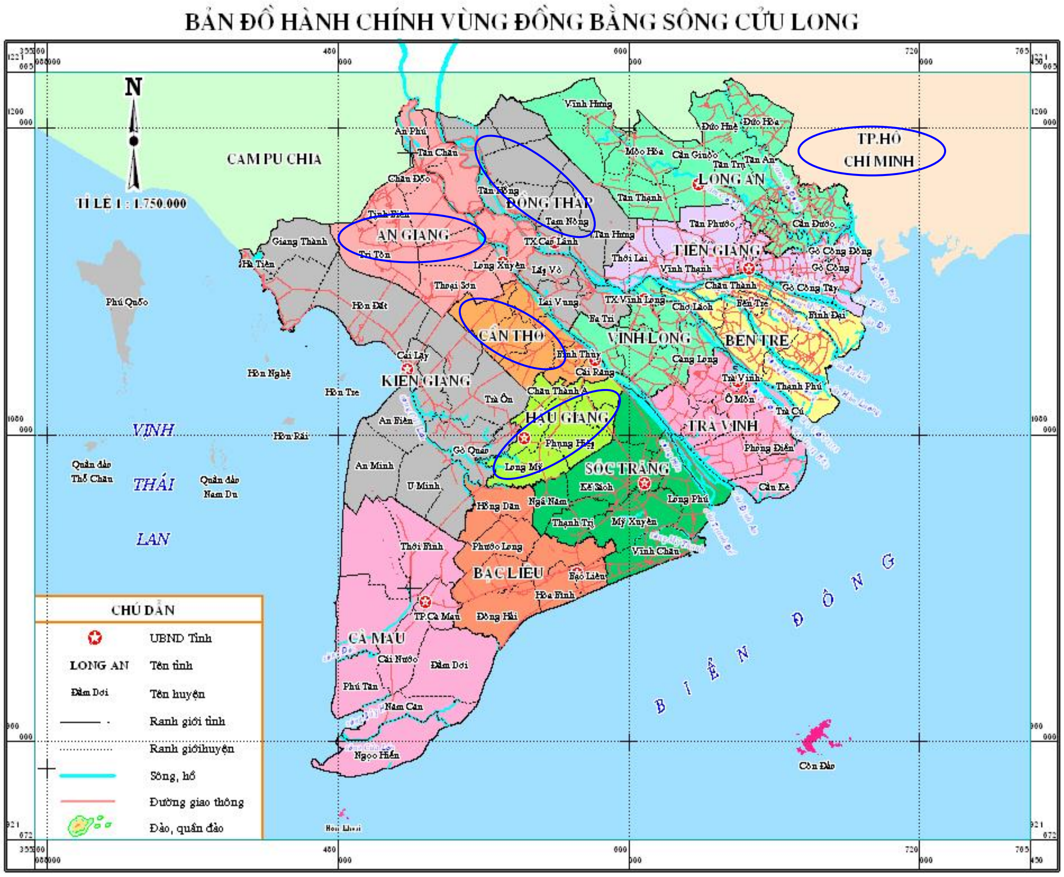

Figure 3: Selected provinces for study in Vietnam

Figure 4: A hatchery of snakehead fish

Figure 5: A farmer with snakeheads cultured in ponds

Figure 6: Preparation of low value fish (golden apple snails) for feeding snakeheads

Figure 7: Harvested snakeheads are prepared for transportation to the market by truck

Figure 8: Traders of dried and fermented snakeheads

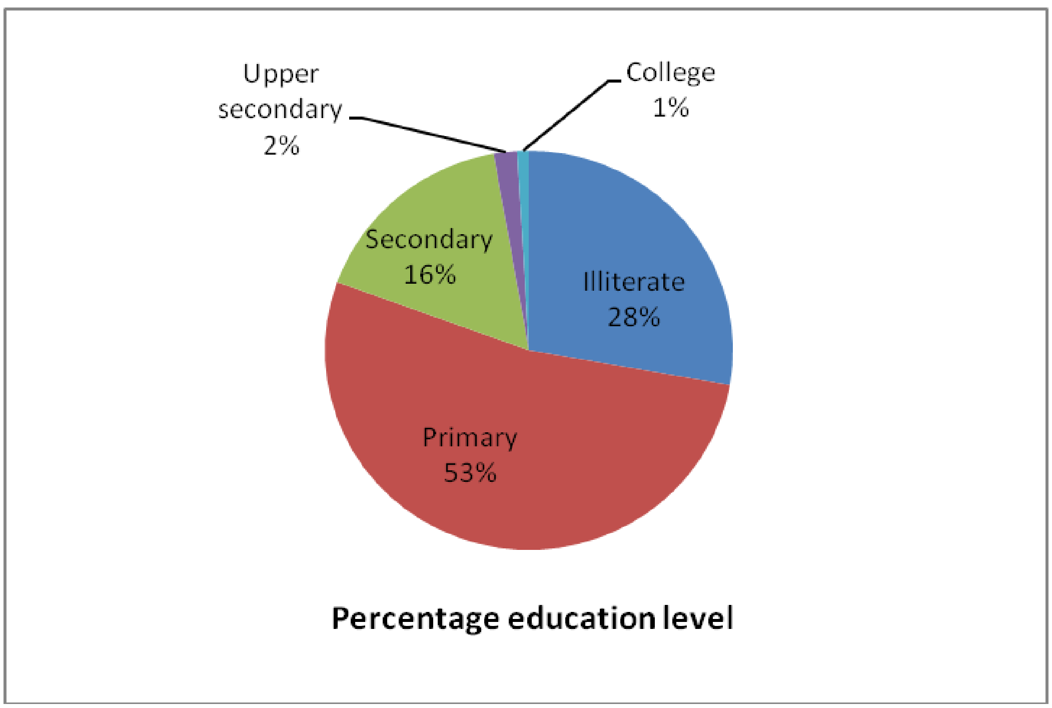

Figure 9: Percentage education distribution of fisher headed household

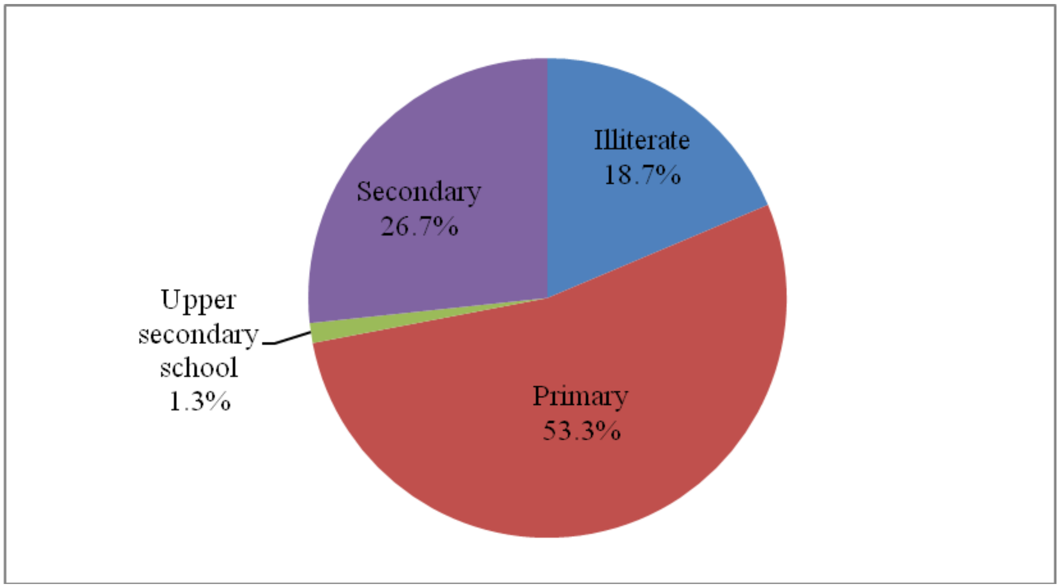

Figure 10: Educational level of fish farmers (%)

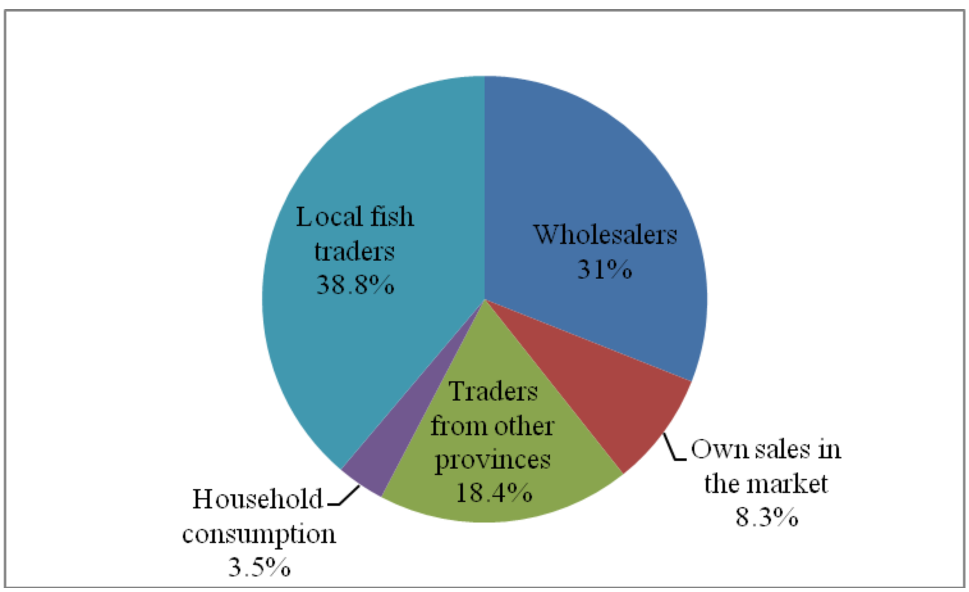

Figure 11: Distribution of captured fresh snakeheads (% of total quantity)

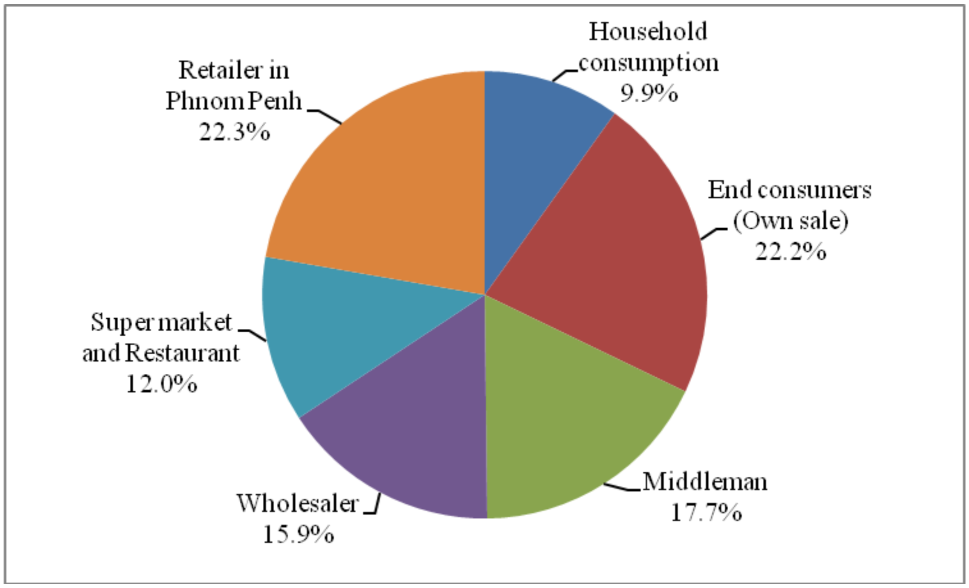

Figure 12: Distribution of salted-dried snakeheads (% of total quantity)

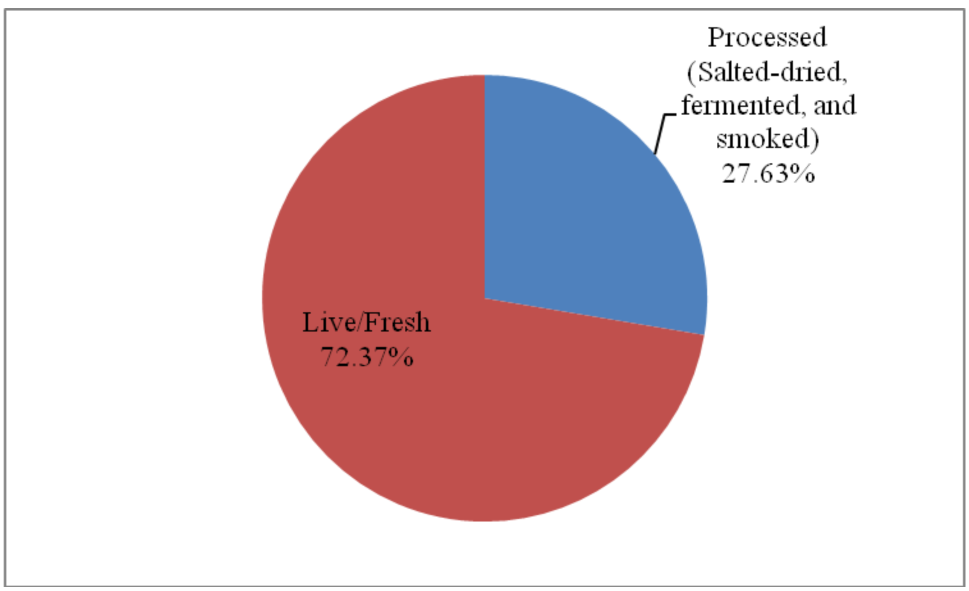

Figure 13: Household consumption of snakehead products (% of total quantity)

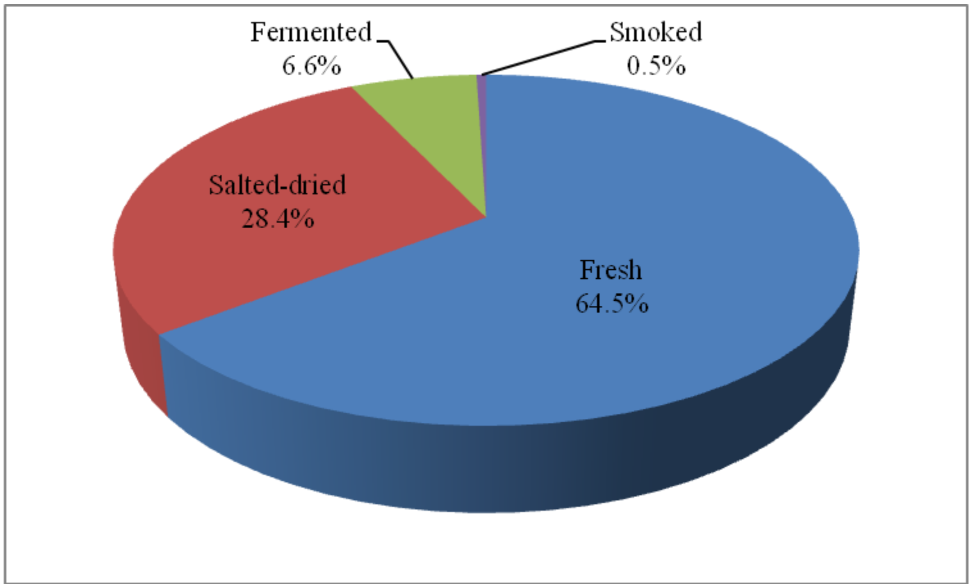

Figure 14: Consumers' preference on different types of snakehead products

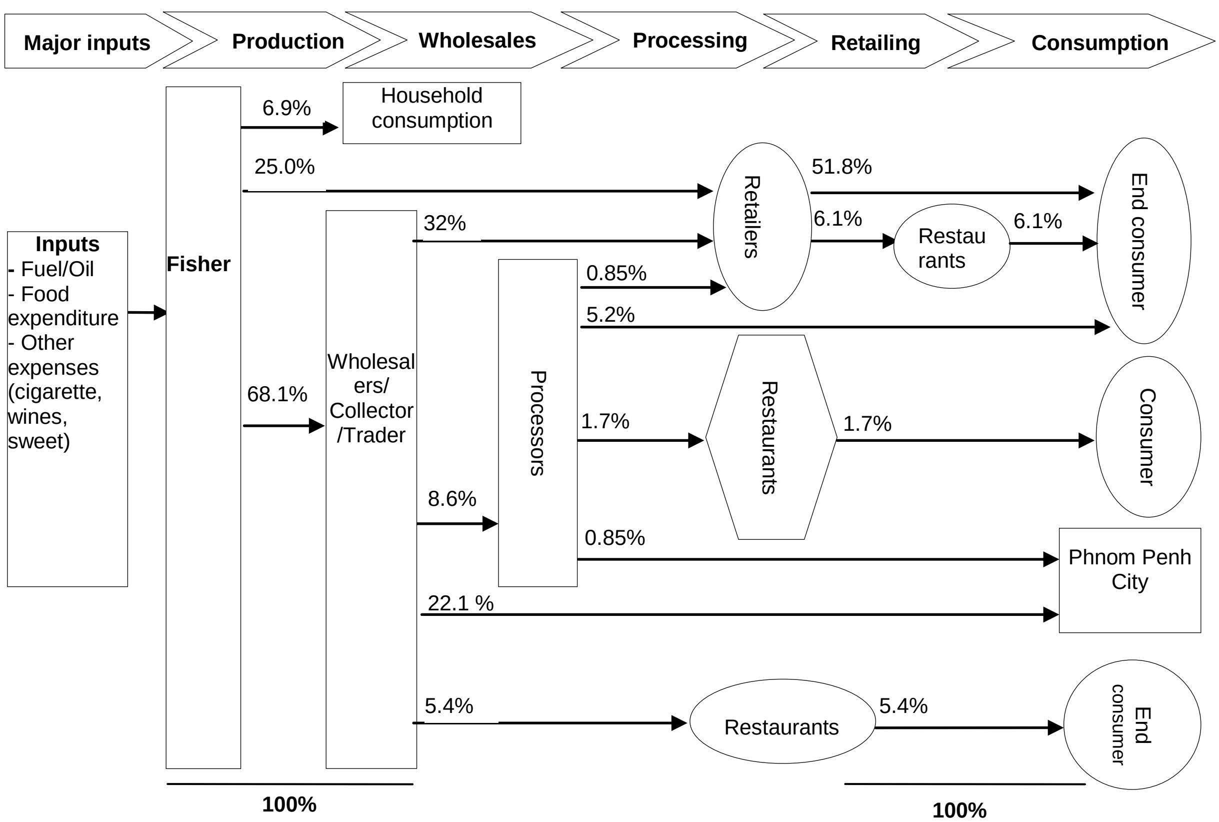

Figure 15: Mapping of value chain of captured snakeheads in the LMB of Cambodia

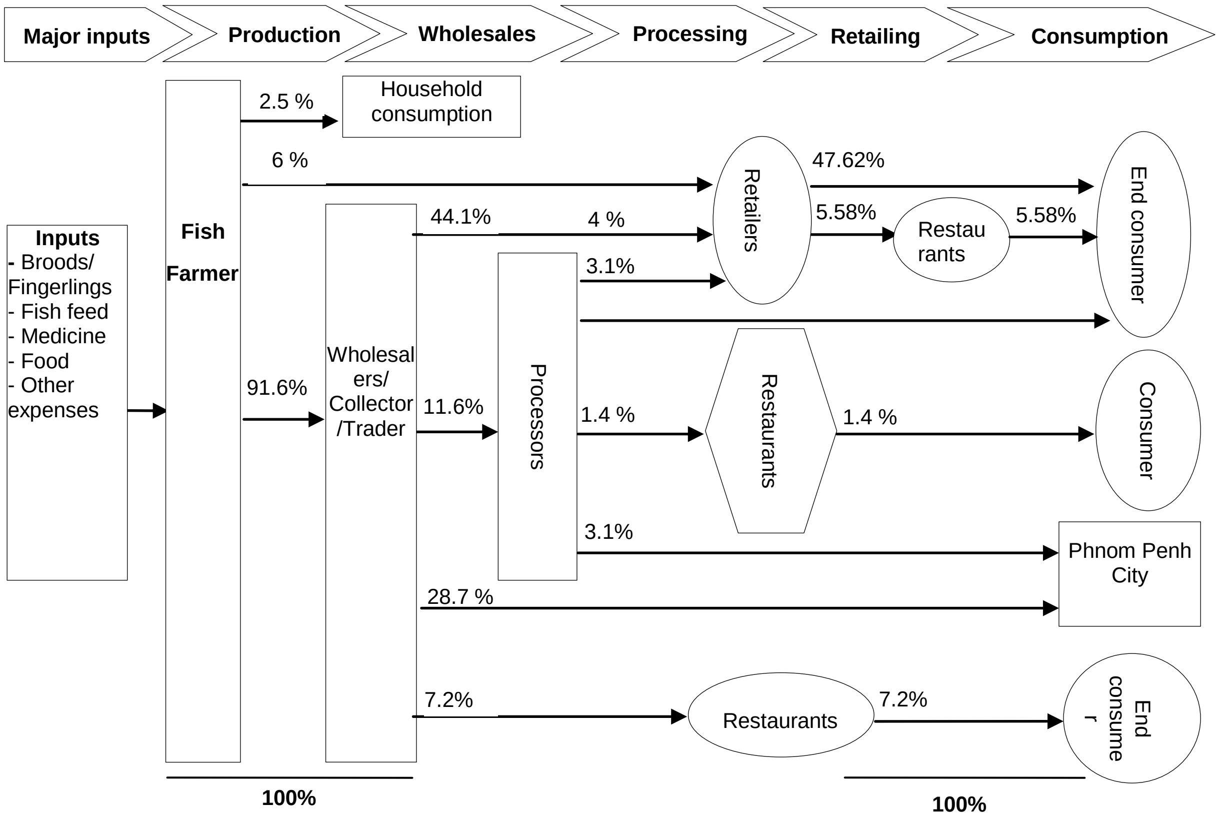

Figure 16: Mapping of value chain of cultured snakeheads in the LMB of Cambodia

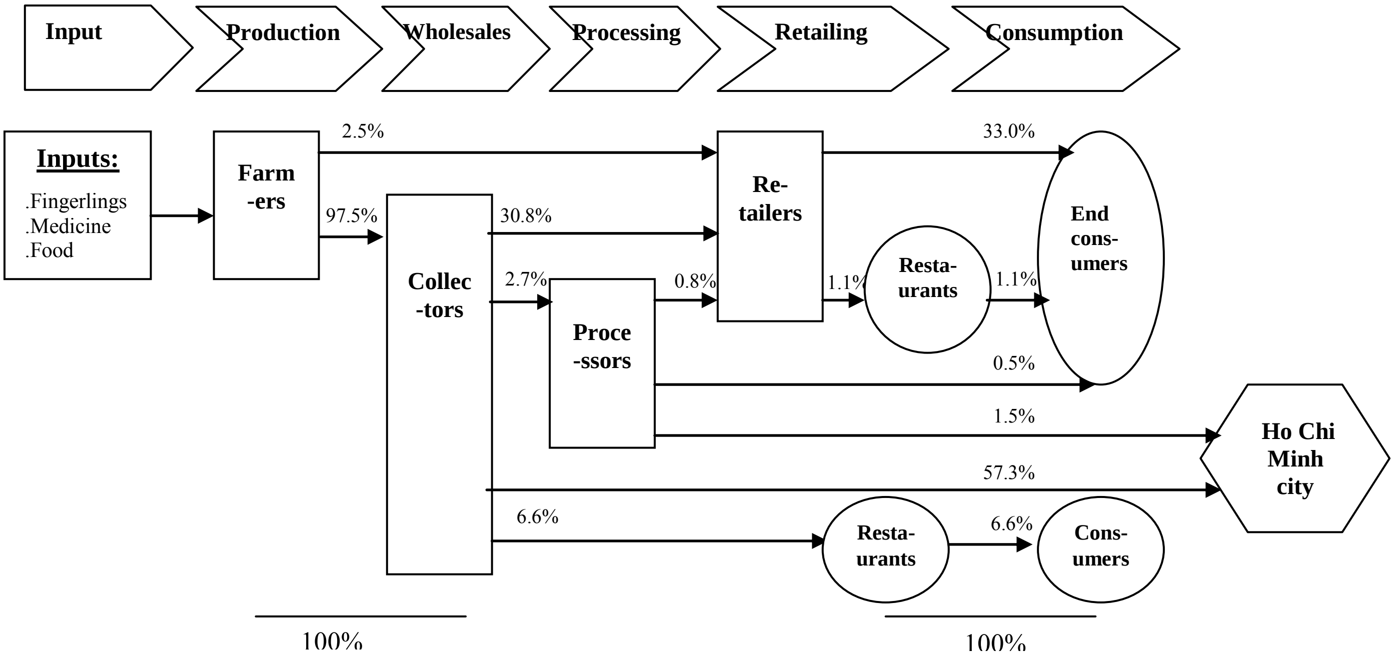

Figure 17: Mapping of value chain of cultured snakeheads in the LMB of Vietnam

Table 1: Distribution of costs and benefits the chain actors of captured snakeheads in Cambodia

Description	Fishers	Wholesalers	Processors	Retailers	Total
Channel 3: **Fishers -> Wholesalers -> Retailers -> Consumers**					
Selling price	1.62	2.11		2.93	
Buying costs	0.57	1.62		2.11	
Added costs	-	0.02		0.25	
Net added value	1.05	0.47		0.57	2.09
% of net added value	50.24	22.49		27.27	100.00
Production/HH/year (ton)	1.41	96.36		5.70	
Total profit (USD/year)	1,480.50	45,289.20		3,249.00	50,018.70
% of NAV/HH/year	3.0	90.54		6.50	100.00
Channel 5: **Fishers -> Wholesalers -> Processers -> Retailers -> Consumers**					
Selling price (USD)	1.62	2.11	2.65	3.11	
Buying costs (USD)	0.57	1.62	2.11	2.65	
Added costs	-	0.02	0.15	0.25	
Net added value	1.05	0.47	0.39	0.25	2.16
% of net added value	48.61	21.76	18.06	11.57	100.00
Production/HH/year (ton)	1.41	96.36	2.40	2.50	
Total profit(USD/year)	1,480.50	45,289.20	1,776.00	2,500.00	51,045.70
% of NAV/HH/year	2.90	88.72	3.48	4.90	100.00
Channel 10: **Fishers-> Wholesalers -> Phnom Penh City**					
Selling price	1.62	2.11			
Buying costs	0.57	1.62			
Added costs	-	0.02			
Net added value	1.05	0.47			1.52
% of net added value	69.08	30.92			100.00
Production/HH/year (ton)	1.41	96.36			
Total profit (USD/year)	1,480.50	45,289.20			46,769.70
% of NAV/HH/year	3.17	96.83			100.00

Table 2: Distribution of costs and benefits the chain actors of cultured snakeheads in Cambodia

Description	Farmers	Wholesalers	Processors	Retailers	Total
Channel 3: **Farmers -> Wholesalers -> Retailers -> Consumers**					
Selling price	1.98	2.11		2.93	
Buying costs	1.56	1.98		2.11	
Added costs	-	0.02		0.25	
Net added value	0.42	0.11		0.57	1.10
% of net added value	38.06	10.00		51.94	100.00
Production/HH/year (ton)	1.80	96.36		5.70	
Total profit (USD/year)	756.00	10,572.90		3,249.00	14,577.90
% of NAV/HH/year	5.19	72.53		22.29	100.00
Channel 5: **Farmers-> Wholesalers -> Processers -> Retailers -> Consumers**					
Selling price (USD)	1.98	2.11	2.65	3.11	
Buying costs (USD)	1.56	1.98	2.11	2.65	
Added costs	-	0.02	0.15	0.25	
Net added value	0.42	0.11	0.39	0.25	1.17
% of net added value	35.90	9.40	33.33	21.37	100.00
Production/HH/year (ton)	1.80	96.36	2.40	2.50	
Total profit (USD/year)	751.92	10,572.90	1,776.00	2,500.00	15,600.82
% of NAV/HH/year	4.82	67.77	11.38	16.02	100.00
Channel 10: **Farmers-> Wholesalers -> Phnom Penh City**					
Selling price	1.98	2.11			
Buying costs	1.56	1.98			
Added costs	-	0.02			
Net added value	0.42	0.11			0.53
% of net added value	79.20	20.80			100.00
Production/HH/year (ton)	1.80	96.36			
Profit/kg (USD)	0.42	0.11			0.53
Total profit (USD/year)	751.92	10,572.90			11,324.82
% of NAV/HH/year	6.64	93.36			100.00

Table 3: Frequency and amount of products per purchase of households in the LMB of Vietnam

Type of products	Rural households (n_1=109)	Urban households (n_2=47)
Seafood/marine fish	0.6 kg/time; 5 times/month	0.8 kg/time; 4 times/month
Freshwater fish	0.6 kg/time; 15 times/month	0.8 kg/time; 11 times/month
Poultry	0.9 kg/time; 3 times/month	1.1 kg/time; 3 times/month
Eggs	10 eggs/time; 5 times/month	8 eggs/time; 5 times/month
Pork	0.6 kg/time; 8 times/month	0.8 kg/time; 11 times/month
Beef	0.5 kg/time; 3 times/month	0.7 kg/time; 4 times/month

Table 4: Distribution of benefits and costs for the chain actors of cultured snakeheads in Vietnam

Description	Farmer	Wholesaler	Processor	Retailer	Total
Channel 3: ***Farmer -> Wholesaler -> Retailer -> Consumer***					
Selling price (USD/kg)	1.65	1.77		2.4	
Buying cost (USD/kg)	1.4	1.65		1.77	
Added cost (USD/kg)	-	0.051		0.08	
Net added value (VND/kg)	0.251	0.069		0.554	0.874
% Net added value (%)	28.8	7.8		63.4	100
Output/actor/year (tons)	14.1	728.2		6.0	
Total profit/actor/year (USD)	3,542.86	49,931.43		3,325.71	
% Net added value/agent/year	6.2	87.9		5.9	100.0
Channel 5: ***Farmer -> Wholesaler -> Processing -> Retailer -> Consumer***					
Selling price (USD/kg)	1.65	1.77	2.06	2.67	
Buying cost (USD/kg)	1.4	1.65	1.77	2.06	
Added cost (USD/kg)	-	0.051	0.223	0.177	
Net added value (USD/kg)	0.251	0.069	0.074	0.429	0.823
% Net added value (%)	30.6	8.3	9.0	52.1	100
Output/actor/year (tons)	14,1	728.2	8.7	1.6	
Total profit/actor/year (USD)	3,542.86	49,931.43	645.71	685.71	
% Net added value/agent/year	6,5	91,1	1.2	1.3	100,0
Channel 9: ***Farmer -> Wholesaler -> HCM city***					
Selling price (USD/kg)	1.65	1.77			
Buying cost (USD/kg)	1.4	1.65			
Added cost (USD/kg)	-	0.051			
Net added value (USD/kg)	0.251	0.069			0.32
% Net added value (%)	78.6	21.4			100
Output/actor/year (tons)	14.1	728.2			
Total profit/actor/year (USD)	3,542.86	49,931.43			
% Net added value/agent/year	6.6	93.4			100.0

Effects of Watershed-Water Quality-Aquaculture Interactions on Quantity and Quality of Water from Small Catchments in South Africa and Uganda

Watershed & Integrated Coastal Zone Management/Experiment/09WIZ01AU

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ABSTRACT

The study reveals that water level declines caused by water withdrawal for irrigation could negatively impact aquaculture in multipurpose impoundments. Aquaculture activities in such impoundments might increase plankton production and the planktonic particles could clog irrigation systems. Changes in water quality caused by aquaculture might also negatively impact use of water for domestic purposes. Nevertheless, these effects could be mitigated, and small impoundments seem to be an excellent way of increasing water supply in rural areas. Construction of small impoundments would convert land to aquatic habitat, but overall, the effort probably would increase local ecosystem complexity and be beneficial to biodiversity.

INTRODUCTION

Acquisition of sufficient water and food for the growing human population is a major issue worldwide and especially in Africa. The traditional way of increasing water supply has been construction of dams on major rivers to impound runoff (Gleick 2004). However, impoundments can be built on small watersheds to impound storm runoff. Such small dams can provide water for agriculture, aquaculture, and community use (Boyd et al. 2010).

In the region around Stellenbosch, South Africa, many small dams have been built to provide water for irrigation, and in recent years, trout have been produced in cages in some of the these reservoirs (Salie 2011; Salie et al. 2008; Maleri et al. 2008). This area could provide a model for construction of multipurpose reservoirs in other regions of Africa.

The purpose of the present study was to make an evaluation of farm dams in the Stellenbosch region with respect to water storage and use, water quality in ponds with and without aquaculture, effects of ponds on local ecosystems with emphasis on biodiversity, and to determine effects of current water use in these impoundments on other possible uses of the water.

MATERIALS AND METHODS

Description of ponds and study areas

Three control ponds and three ponds with cage culture were selected. These six ponds are sited on five farms that are located within a 35-km radius of Stellenbosch in the Boland area of the Western Cape Province of South Africa. Stellenbosch region soils developed from a variety of geological materials. The oldest rocks are sedimentary formations of the Malmesbury Group consisting of shales, schists, and greywacke (Theron et al. 1992). The Malmesbury sediments folded into chains of small mountains and were intruded by granite. The landscape eventually subsided and was covered by sands and shales. Erosion of the sands and shales exposed the remnants of the Table Mountain Group and low granite hills and in front of these formations the coastal plain of the Western Cape developed (Theron et al. 1992).

Farms for this study are on the slopes between the mountains and granite hills (Stellenbosch, Helderberg, Simonsberg, and Drakenstein Ranges) and the coastal plain. Soils on these slopes tend to be highly weathered, sandy, and acidic (pH 5-5.5), and they contain considerable quantities of stone (Conradie et al. 2002). Soils are of the Tukulu, Vilafontes, Avalon, Oakleaf, Glenrosa, Hutton, and Westleigh types.

Climate in the Western Cape region is classified as mild Mediterranean with mean monthly temperatures between 13°C in September and 22°C in February (Conradie et al. 2002), and rainfall measures up to about 1,000 mm/yr (Walkingholidays.co.za). The natural vegetation is known as fynbos that consists of fine-leafed, thick, shrub-like plants, but much of this vegetation has been replaced with alien species – eucalyptus, acacias, pine, oaks, poplars, fruit trees, pasture grasses, vineyards, and exotic weeds. Because of high water use by alien plants compared to native, fynbos vegetation (Dye and Versfeld 2007), the South African government has initiated programs to remove alien species from areas not devoted to agriculture and forestry and re-establish fynbos vegetation on these tracts.

Specific information on ponds and watersheds is provided in Table 1. The ponds under the heading cages were sites for cage culture of rainbow trout. The estimated production of trout in 2010 was 6,000 kg in Mountain Vineyards, 12,000 kg in Patryskloof, and 18,000 kg in Blue Gum. Trout fingerlings were stocked in April and fed three times daily with a 38% crude protein content, pelleted feed at about 3% of estimated body weight per day. Marketable-sized trout were harvested between October and December.

Water analyses

Water samples were collected by dipping water from pond surfaces at monthly intervals from January to August 2011. These samples were analyzed for pH, temperature, dissolved oxygen, electrical conductivity, total alkalinity, total hardness, total phosphorus, total ammonia nitrogen, nitrate-nitrogen, nitrite nitrogen, iron, manganese, zinc, and copper (Eaton et al. 2005). The Secchi disk visibility also was measured on each sampling date.

Hydrologic measurements

Historical data on air temperature, rainfall, and Class A pan evaporation in the area were available from Conradie et al. (2002), but data specifically for the study ponds were unavailable. Watershed runoff was estimated by the water accounting method described by Yoo and Boyd (1994). The Thornthwaite method (Thornthwaite and Mather 1957) allowed calculation of monthly evapotranspiration rates needed in the water accounting method for estimating runoff.

Pond water levels were measured at weekly intervals from 19 January to 1 September 2011 with aid of a modified staff gauge. Project funds were inadequate to allow installation of water flow measuring devices for inflow of streams to ponds, overflow from ponds, and water removed from ponds for use in irrigation. Pond capacities and areas at full-pool level were obtained from design drawings for original pond construction.

Watershed observations

The areas of watersheds were delineated from satellite imagery, and the shoreline distances of ponds were also obtained from these images. Watershed cover was assessed visually. Farmers provided information about land use management practices on watersheds.

RESULTS

Watersheds and ecology

Only two of the farms, Vergelegen and Boschendal, had significant area of native fynbos vegetation; the other watersheds were devoted almost entirely to forestry and agriculture (Table 1). All farms had agricultural activities on pond watersheds, and fertilizers and pesticides were routinely applied to crops. The common pesticides used and active ingredients in them are presented in Table 2:

Ponds were located in former agricultural land, and pond construction resulted in disruption of the areas around the ponds. The denuded areas typically were invaded by alien species, especially weeds. The pond water levels decline greatly during the dry season exposing large areas of denuded soil, but because of lack of moisture, these areas do not re-vegetate before ponds are refilled by runoff during rainy months.

Ponds in humid climates typically have wetland areas around edges and in upper ends where water inflow tends to be greatest (Chaney et al. 2012). Because of the rapid and great change in water level during the dry season when water is removed for irrigation, wetland areas have not developed around the edges of ponds selected for this study. Wetland vegetation has developed in small water courses that conveyed water into ponds and received pond overflow during the wet season. These areas ranged in size from 1,000 m^2 to about 5,000 m^2 in the inflow and outflow zones of each pond.

Water sources for the ponds are: direct rainfall, sheet flow runoff from watersheds, groundwater seepage during the wettest periods (De Groeve 2003), and inflow of ephermal streams. Inflowing streams had diversion structures that conveyed a portion of their flow away from ponds and into the natural watercourse to maintain downstream flow.

A number of species of wetland plants were observed in the inflow and outflow areas to include *Typha capensis*, *Scirpus* sp., *Zantedeschia arthiopica*, *Pteridium* spp., *Phragmites* australis, *Ischryro lepis*, *Restio* sp.; *Cliffortia* spp., *Pennisetum macrourum*, *Senecio halimnifolius*, *Juncus karusii*, and *Passerina paludosa*. These plants created habitat for amphibians, reptiles and small birds.

The open water areas of the ponds created habitat for birds. Herons, kingfishers, Egyptian geese, fish eagles and cormorants were observed in and around the ponds. Frogs were seen in the ponds, and deer, baboons, and several species of small mammals were observed drinking water from the ponds.

The ponds also contain fish that have been stocked purposely (in addition to those used in aquaculture cages) or entered naturally. The fish include bass, carp, tilapia, and catfish, and trout.

These observations suggest that the ponds have increased the amount of aquatic habitat and enhanced biodiversity in the study area. In addition, they provide irrigation water critically needed for crops and allow the possibility for commercial aquaculture. The ponds also could supply water for livestock and domestic use if necessary.

Water balance

None of the ponds had water pumped into them from other ponds or streams during the study. However, it is not uncommon at some ponds in the area for farmers to pump water from streams into ponds to supplement water entering from watersheds.

There was no feasible way to estimate the quantity of water diverted from ponds to support downstream flow. Thus, it was impossible to obtain sufficient data for making detailed water budgets for the ponds as originally planned. We had to focus on estimating the water balance for hypothetical, 1-ha watershed units and 1-ha pond units for conditions existing in the Stellenbosch region.

Net seepage from ponds in the area was estimated to be 190 mm/month (De Groeve 2003). These data allowed an estimation of the water balance (excluding runoff into ponds) for a 1-ha area of pond surface. Inflow by rainfall would average 6,910 m^3/ha/yr, but outflow through seepage and evaporation would be 35,230 m^3/ha. Thus, the water balance is -28,320 m^3/ha. The water for replacing seepage and evaporation losses and maintaining pond volume must be provided by runoff from pond watersheds.

The average moisture holding capacity of soils in the study area was reported to be about 125 mm/m of soil depth and the plant root zone extends to roughly 1 m in the soil (Conradie et al. 2002). This information allowed runoff to be estimated by the moisture accounting method (Table 3). Runoff will occur in June, July, August, and September, and the average annual runoff should be about 153 mm (about 22% of annual rainfall) or 1,530 m^3/ha/yr. Thus, 18.5 ha of watershed would be necessary to provide enough runoff to compensate for the excess of seepage plus evaporation over direct rainfall into ponds. An additional 6.5 ha of watershed would be needed for each 1 m depth of storage volume over 1 ha of pond surface area. Thus, a 10-m deep pond would require a watershed area of 83.5 ha/ha of water surface area.
Calculations above assume that the entire watersheds of ponds were located on the slopes of the granite mountains at the upper ends of the watersheds. However, a portion of all watersheds was located on the mountains, but the area of the watersheds that consisted of granite outcrops could not be estimated from the maps and satellite images available.

The moisture holding capacity of these granite outcrop areas is essentially nil. The runoff estimations should be adjusted for these areas, because almost all of the rain falling on rock outcrops would be converted to runoff. To illustrate the problem with runoff estimates, Patryskloof Dam at Cape Olive Farm is 4 m average depth and has a watershed area of 530 ha. Based on the runoff estimate (Table 3), this pond would need 132.5 ha of watershed area, and it has 530 ha. This pond has plenty of watershed area to fill in a normal year. However, Ashanti Dam at Ashanti Farm would need 1,707 ha of watershed to fill on a normal year, and the watershed area provided by the farm manager is only 320 ha. Nevertheless, this pond fills with water. Obviously, we need to obtain more accurate data on watershed areas and watershed soils in order to assess runoff more accurately.

Water levels

Water levels decreased steadily during the period January through May. However, water levels began to increase in June in response to greater rainfall, lower evaporation rates, and cessation of water removal for irrigation during the winter. By September, water levels were near the levels observed in January.

Water quality

Water quality data are summarized in Table 4. Although there were no large differences among ponds within the control group and the aquaculture group or between the two groups, there was a tendency of greater ammonia and nitrate concentrations in the ponds with aquaculture. This is not surprising considering that feeds were applied to the cages. Earlier studies are in agreement and suggested that feed inputs also lead to greater phytoplankton productivity (Maleri et al. 2008).

The water quality in the ponds also was suitable for livestock watering and many other domestic uses. For use in households, the water probably would need to be clarified by alum treatment and boiled or treated with chlorine to assure a sanitary condition.

DISCUSSION

Although it was impossible to make a detailed water budget for each pond because of the lack of accurate information on water withdrawal and diversion from ponds for irrigation and downstream flow, the study revealed that these multipurpose ponds had drastic declines in water level as a result of water use for irrigation. Although trout culture was possible because water levels remained fairly high during the cooler part of the year, such ponds, if located in warmer climates might not be suitable for aquaculture because of poor water quality and crowding of fish when water levels are low. Of course, cage culture would be possible during periods when water levels are high.

The ponds resulted in conversion of land to water surface, but in the semi-arid climate of South Africa, the formation of permanent water surfaces and small areas of wetland associated with the ponds is no doubt beneficial by creating an ecosystem complexity and increasing biodiversity.

The main purpose of ponds in this study was for irrigation, and nutrients from aquaculture would possibly enhance the benefits obtained from the water for this purpose. However, it has been suggested in earlier studies that increased phytoplankton production in ponds as a result of aquaculture could result in clogging or irrigation systems (Koegelenberg et al. 2002; du Plessis 2007). Aside from possibly clogging irrigation systems, eutrophication of ponds likely would not be of other concern in the Stellenbosch area. In other areas where pond water would be used for domestic purposes in addition to irrigation, eutrophication would possibly be of other concerns such as excessive turbidity, undesirable color, and taste and odor problems.

ANTICIPATED BENEFITS

This study suggests that multipurpose ponds could be a valuable water supply for many rural areas and especially in African countries. Construction of such ponds would cause changes in land use – terrestrial habitat to water surfaces and wetlands. Nevertheless, the inclusion of such areas in the landscape would have a beneficial effect on local ecosystems. However, such projects would be hydrologically complex, and much more research is needed for development of guidelines for pond site selection, design, construction, and operation.

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Table 1. Description of ponds used in study of water quality, hydrology, and watersheds in Stellenbosch region of South Africa. The controls had no aquaculture, but trout were produced in cages in the ponds listed under aquaculture.

Name of Pond	Farm	GPS coordinates	Area (ha)	Volume (m^3)	Average depth (m)	Shoreline (m)	Watershed cover
Controls							
Rooiland	Vergelegen	34° 4' 52.14" S 18° 54' 38.72" E	23.7	2,700,000	11.4	2,240	Fynbos and vineyard
Normandie	Boschendal	33° 53' 12.97" S 18° 59' 5.77" E	11.8	720,000	6.1	1,500	Fynbos and vineyard
Ashanti	Ashanti	33° 43' 35.425" S 19° 1' 52.21" E	14.3	1,170,000	8.2	2,000	
Aquaculture							
Blue Gum	Lourensfard	34° 1' 55.07" S 18° 55' 54.49" E	16.8	1,700,000	10.1	1,980	Olive, fruit, eucalyptus, pine trees, and vineyard
Mountain Vineyards	Boschendal	33° 52' 24.88" S 18° 57' 20.43" E	8.0	675,000	8.4	1,370	Fruit trees, vineyards, and pasture
Patryskloof	Cape Olive	33° 42' 26.19" S 19° 2' 1.23" E	7.0	280,000	4.0	1,160	Olive trees

Table 2. List of pesticides used on farms that could possibly have entered waters.

Type	Product	Active ingredient
Fungicide	Kumulus	Sulphur
	Vivando	Metrafenone
	Cabrio	Strobulin
	Talendo	Penconazole
	Svitch	Fudioxinil ciprodinyl
	Topaz	Pencanozole
	Mancozeb	Dithiocarbamate
	Captab	Calcium polycarbophil
Insecticide	Proandub	Glyfosate
Herbicide	Gramoxone (preglove)	Paraquat dichloride
	Fuzilade	Flazifop-p-butyl
	Aromasin	Exemestane

Table 3. Estimation of runoff by the soil moisture accounting method.

	Month											
Variable (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Soil moisture at beginning month	0	0	0	41	125	125	125	125	105	77	8	0
Rain during month	16	48	88	140	95	96	60	42	45	31	18	12
Total available moisture for month	16	48	88	181	220	221	185	167	150	108	36	12
Potential evapotranspiration during month	82	63	47	36	34	44	40	62	73	100	102	102
Soil moisture remaining at end of month	0	0	41	145	186	177	145	105	77	8	0	0
Soil moisture holding capacity of soil	125	125	125	125	125	125	125	125	125	125	125	125
Runoff during month	0	0	0	20	61	52	20	0	0	0	0	0

Table 4. Water quality data for ponds with cage culture and without cage culture.

	Cages			Controls		
Variable	Mountain Vineyards	Cape Olive	Blue Gum	Normandi	Ashanti	Rooiland
Temperature (^{o}C)	19.8 ± 3.4	18.6 ± 2.6	20.9 ± 4.5	20.4 ± 2.6	20.3 ± 2.7	20.8 ± 2.5
Dissolved oxygen (mg/L)	8.25 ± 0.67	8.54 ± 0.91	9.26 ± 1.11	7.93 ± 0.52	8.68 ± 0.64	
pH	7.09 ± 0.36	7.22 ± 0.32	7.40 ± 0.06	7.00 ± 0.20	7.57 ± 0.37	7.27 ± 0.20
Secchi disk (cm)	124 ± 59	58 ± 36	147 ± 90	144 ± 168	96 ± 49	57 ± 27
Conductivity (mS/m)	7.28 ± 0.79	8.81 ± 1.20	5.70 ± 1.18	4.33 ± 0.72	13.16 ± 0.94	15.14 ± 1.78
Total alkalinity (mg/L)	12.5 ± 2.7	8.4 ± 0.8	6.1 ± 1.6	4.1 ± 0.7	18.8 ± 1.6	14.1 ± 0.8
Total hardness (mg/L)	16.1 ± 2.4	17.7 ± 6.2	15.9 ± 3.2	12.5 ± 2.9	25.4 ± 4.6	17.7 ± 3.5
Phosphorus (mg/L)	0.018 ± 0.025	0.018 ± 0.021	0.028 ± 0.038	0.014 ± 0.018	0.042 ± 0.045	0.015 ± 0.020
Total ammonia N (mg/L)	0.33 ± 0.16	0.31 ± 0.13	0.56 ± 0.38	0.19 ± 0.08	0.40 ± 0.16	0.27 ± 0.12
Nitrate N (mg/L)	0.75 ± 0.76	0.15 ± 0.20	0.18 ± 0.19	0.13 ± 0.11	0.40 ± 0.43	0.22 ± 0.15
Nitrite N (mg/L)	0.014 ± 0.006	0.021 ± 0.007	---	0.023 ± 0.017	0.030 ± 0.020	---
Iron (mg/L)	0.079 ± 0.042	0.387 ± 0.105	0.463 ± 0.451	0.296 ± 0.384	0.537 ± 0.594	0.540 ± 0.220
Manganese (mg/L)	0.001 ± 0.002	0.002 ± 0.002	0.016 ± 0.019	0.020 ± 0.020	0.082 ± 0.120	0.010 ± 0.011
Copper (mg/L	0.003 ± 0.003	0.002 ± 0.002	0.001 ± 0.001	0.006 ± 0.007	0.002 ± 0.003	0.003 ± 0.005
Zinc (mg/L)	0.005 ± 0.004	0.006 ± 0.003	0.009 ± 0.003	0.010 ± 0.003	0.012 ± 0.006	0.004 ± 0.003

Surface Catchment Development and Sustainability Evaluation for Multipurpose Water Supply for Meeting Aquaculture and Other Water Needs

Watershed & Integrated Coastal Zone Management/Study/09WIZ02AU

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ABSTRACT

Fish farming in Uganda is predominantly practiced by poor people in villages for subsistence with 80 % of the ponds about 100 m². Many of the ponds are just dug in swampy/wetland areas or micro-watershed concentrated storm runoff areas without proper planning or guidelines that take into considerations the ecological and environmental impacts. This has led to drying up of ponds and massive encroachment on wetlands and riparian buffers. Also, on the national coverage, there was no detailed map of Uganda depicting areas that are suitable for inland fish farming while accounting for the need to control encroachment on wetlands and riparian buffers. The project goal was to develop strategies to better employ water capture in Uganda by modeling for surface catchment and site evaluation in the presence of potential surface water runoff. The specific objectives included: (1) use of geographic information systems (GIS) and remote sensing (RS) to develop an aquaculture site suitability map for Uganda; (2) develop guidelines on site selection of ponds to ensure reliable water supply and sustainable ecological existence within the micro-watershed; and (3) construction of pilot pond for demonstration and future instruction purposes. The approach for the physical research began with remote sensing and GIS assessment of site suitability for Uganda with emphasis on soils, topography, climate, access to farm inputs and access to markets. Working with host country personnel, sites were identified for the preliminary screening analysis based on GIS analysis and the spreadsheet tool. Potential sites were further analyzed using infiltration or seepage pits. The major suitability study findings related to the crisp and fuzzy suitability maps developed for Uganda. For both the crisp and the fuzzy approaches, over 98 % of the land was classified as either suitable or as moderately suitable. Overall, the crisp method classified 16,322 hectares (0.09 %) as very suitable compared to zero hectares (0 %) by the fuzzy method. Simultaneously, the crisp method gave 297,344 hectares (1.96 %) as unsuitable compared to 168,592 hectares (0.96 %) by the fuzzy method. Of the 138 surveyed fish ponds that were operational, the crisp method classified 71 % as suitable while 29 % as moderately suitable while the fuzzy method classified 71.7 % as suitable while 28.3 % as moderately suitable. Key concerns regarding pond construction were side slope stabilization and levee compaction. These were extensively emphasized during the host country workshop. For the compaction, farmers expressed interest in a simple manually operated tool that can easily be transported to any site. The second challenge expressed by visited farmers was excess water during the wet months and drying up of ponds during the dry months.

INTRODUCTION

Background and Problem Definition

Agriculture is the most important sector of Uganda's economy and accounts for over 31 % of the country's export earnings, contributes 32 % to total GDP and Provides 80 % of employment (World Bank report, 2007). Because of this central and strategic role of agriculture to the national economy, it is the key to; improvement in economic performance; increased incomes; raising of living standards of households; ensuring food security and poverty eradication. A major component for development of the agricultural sector is the development and sustainable utilization of water resources. Although the country is usually considered as being well endowed with water resources (Lake Victoria, River Nile, and annual rainfall in some parts of 1600 mm – 2000 mm) the seasonal and spatial variability of rainfall patterns and stream flows cause specific problems because the country encompasses both humid and semi-arid areas. There are very wet and very dry years, but also considerable variations in the timing of the onset of seasons and the amount of rainfall. This has resulted in repeated cases of severe food shortage due to crop failure coupled with death of a significant number of livestock. One strategic approach to minimize the effects of erratic rainfall patterns on agricultural production and productivity is to integrate watershed management schemes that focus on capturing overland flow in small impoundments for multiple uses such as community water supply, aquaculture, livestock watering, and small-scale irrigation.

Some of the rural population involved in fish farming in Uganda, construct ponds by digging up areas in swampy locations and wetlands without proper siting, design, construction and management. This has led to encroachment, disruption, and destruction of natural wetlands and riparian buffers. Thus, altering and eliminating the natural functionality of wetlands and riparian buffers (which is filtration and settlement of nutrients and sediment respectively). Therefore, demonstration of proper pond siting, construction, management, and provision of guidelines in consultation with local stakeholders will provide alternatives to the above mentioned issues related to unsustainable fish farming practices. The proposed strategy for this project focused on two critical steps. The first step was the utilization of geographic information systems (GIS) and remote sensing to develop a GIS based stratification map of Uganda depicting suitable areas with respect to water availability and other metrics that influence pond based fish farming suitability. The water availability metric accounted for annual water balance, required pond volume, and average farm size. Other metrics addressed suitability related to topography, access to markets, and availability of farm inputs. The second step focused on detailed site survey and analysis for construction of pilot pond.

Purpose, Objectives, Scope: Project goals and objectives

The project goal and scope were to develop strategies to better employ water capture in Uganda by modeling for surface catchment and site evaluation in the presence of potential streams, wetlands and surface water runoff. The specific objectives included

1. Use of geographic information systems (GIS) and remote sensing (RS) to develop an aquaculture site suitability map for Uganda (*Hypothesis: Site suitability for aquaculture is significantly influenced by climate, topography, and soils*).
2. Development of guidelines on site selection for watershed and levee ponds to ensure reliable water supply and sustainable ecological existence within the micro-watershed. The information in the local guidelines does not address proper siting, design, and construction practices (*Hypothesis: Proper siting, design, construction, and maintenance of ponds are key to sustainable fish farming practices with minimal ecological and environmental impacts*).
3. Pond construction to demonstrate proper site selection (based on site suitability map), design, and construction practices that minimize encroachment on wetlands.

METHODS AND MATERIALS

Suitability metrics

Seven criteria of water requirement, water temperature, soil texture, terrain slope, potential farm gate sales, availability of farm inputs, and access to local and regional markets were analyzed for site suitability for Tilapia and Clarias farming. To enable geographic information systems (GIS) operations during the multi criterion evaluation (MCE) process, the criteria thresholds were transformed into crisp and fuzzy set values for comparison. The crisp values used the class limits based on expert knowledge while the fuzzy values allowed for a degree of membership between classes. The crisp values were based on criterion thresholds in table 1 such that values of one, two, three, and four represented not suitable (NS), moderate suitability (MS), suitable (S), and very suitable (VS) respectively. The fuzzy values (ranging from one to four) were generated by using a combination of triangular and trapezoidal membership functions.

Table 1. Summary of crisp values for each suitability group across the seven criteria

	Criterion	Criterion thresholds			
		Very Suitable	Suitable	Moderate Suitability	Not Suitable
1	Water requirement (ha – required drainage area)	< 5	5 - 20	20 - 100	> 100
2	Water Temperature (^{O}C)	28 - 32	24 - 28	20 - 24	< 20 or >32
3	Soil texture (% clay)	15 - 30	10 – 15 or 30 - 40	5 – 10 or 40 - 50	< 5 or >50
4	Slope (%)	< 2	2 - 5	5 - 15	> 15
5	Farm gate sales (people / km^2)	150 - 300	25 - 149	1 - 24	< 1or > 300
6	Access to local and regional markets (travel hours)	< 1	1 - 3	3 - 6	> 6
7	Farm inputs • Total number of poultry • Distance to feed agents (km)	 > 100,000 < 30	 40,000 – 100,000 30 - 50	 15,000 – 40,000 50 - 100	 < 15,000 > 100

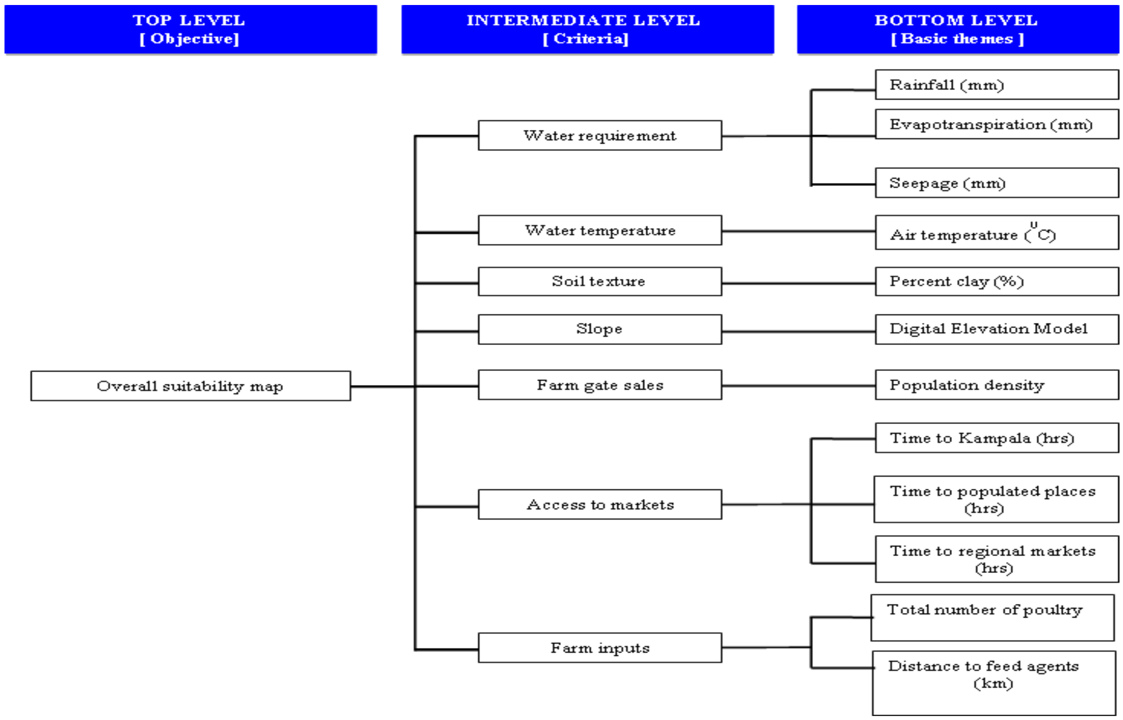

Figure 1. Flow chart of the geospatial modeling process

Data and GIS modeling

Table 1 and figure 1 depict the themes and data used to generate suitability maps for each of the seven criteria and the overall suitability. This study considered water from rainfall runoff as the primary source of water for small scale fish farming. The watershed drainage area required to provide 500 m^3 pond volume during the critical month of the year for each location was used as the metric for water requirement. The seepage values were estimated based on lower limit of seepage rates in Egna and Boyd (1997). The curve number method was used to estimate annual runoff. The curve numbers were determined using the soil hydrologic group, land use, and land cover data.

The soil hydrologic groups were estimated using soil textural classes. MATLAB® functions and scripts were developed to reclassify the soil textural classes into soil hydrologic groups. The soils textural data was extracted from the Harmonized World Series Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2008) while the landcover and landuse from the Food and Agriculture Organization (FAO) Africover multipurpose landcover database (Africover, 2002). Evapotranspiration was estimated by the Blaney – Criddle model. Annual rainfall map of Uganda was generated by interpolating (inverse distance weighing) long term average rainfall data (1961 – 1990) of various rain gauge stations in Uganda (347 stations), Kenya (706 stations), Tanzania (556 stations), Rwanda (40 stations), Sudan (171 stations), and Democratic Republic of Congo (187 stations). The rainfall gauge data was extracted from the FAO Agroclimatic database (FAO, 2010). ArcMap GIS was used to interpolate the above gauge data and to extract the Uganda annual rainfall grid.

Water temperatures were estimated using a mean monthly water temperature model by Kapetsky (1994) that relates water temperatures to air temperatures of 51 data points at the Henderson Research Station near Harare (Zimbabwe). The slope and soil texture suitability (table 1) were classified by modifying ratings by Yoo and Boyd (1993); Hossain et al. (2007); Hossain et al. (2009); and Hossain and Das (2010). Access to farm inputs was estimated using two factors. The first factor quantified the total number of poultry as an indicator of access to feeds. The total numbers of poultry were calculated at a sub-county level and the geo-referenced data were based on the Uganda National Household Survey for Agriculture and Livestock data (IGAD-LPI, 2010).

The second factor was the distance to the location of major feed agents. ArcGIS was used to compute the Euclidean distance to the major feed agents. The overall access to farm inputs was generated by computing for the maximum suitability between the two factors. This project used population density as the metric for potential farm gate sales. The same thresholds used by Kapetsky and Nath (1997); and Aguilar-Manjarrez and Nath (1998) were used. The accessibility metric used was the travel time in hours in contrast to distance because it is a more realistic metric for areas where the quality of transport network is variable (Pozzi et al., 2010). The data used were grid based GIS layers generated by the IGAD Livestock Policy Initiative. Each grid cell represented the time required to reach the nearest point of interest (Kampala or populated areas) along the least cost route (Pozzi et al., 2010).

To enable geographic information systems (GIS) operations during the multi criterion evaluation (MCE) process, the criteria thresholds were transformed into crisp (table 1) and fuzzy set values for comparison. The crisp values used the class limits based on expert knowledge (4 for VS; 3 for V; 2 for MS; and 1 for NS) while the fuzzy values allowed for a degree of membership between classes.

Design workshop and pond construction

A two day workshop was held at the host institution (Makerere University, Uganda) that brought together the major stakeholders (researchers from local institution, fish farmers, and U.S. lead advisors). The first day focused on the state of aquaculture, water availability, pond construction challenges, and use of GIS and RS in site selection. The second day focused on preliminary site assessment, in-situ measurements such as use of seepage pits, and use of spreadsheet tools for water balance and design of levee and watershed ponds. Throughout the workshop, encroachment on wetlands and riparian buffers was discouraged. A compact disc of the guidelines and design strategies was given to each participant for future reference. The workshop material emphasized: Site description (topography, photo and images showing surrounding land, climate description with monthly rainfall and evaporation values from surrounding stations, riparian zone around the pond site); Soils (texture and infiltration pit study results); Design (selected size, depth, inlet works, and outlet works); Construction (timing and photograph sequence, excavation methods, and compaction techniques); and operational plans (water quality studies, integrated fish production and riparian zone management, and riparian zone effects). The primary pond excavation, side slope and levee compaction were manually achieved. We followed recommendations that are summarized in Coche (1988) and Coche et al (1995).

RESULTS

Table 2. Summary of overall Tilapia and Clarias suitability classification by the crisp and fuzzy methods

	Crisp		Fuzzy	
	Area (hectares)	Area (%)	Area (hectares)	Area (%)
Not suitable	10,794	0.06	7,150	0.04
Moderate suitability	8,380,709	47.62	8,676,808	49.30
Suitable	9,147,925	51.98	8,914,442	50.65
Very suitable	59,203	0.34	230	0.00

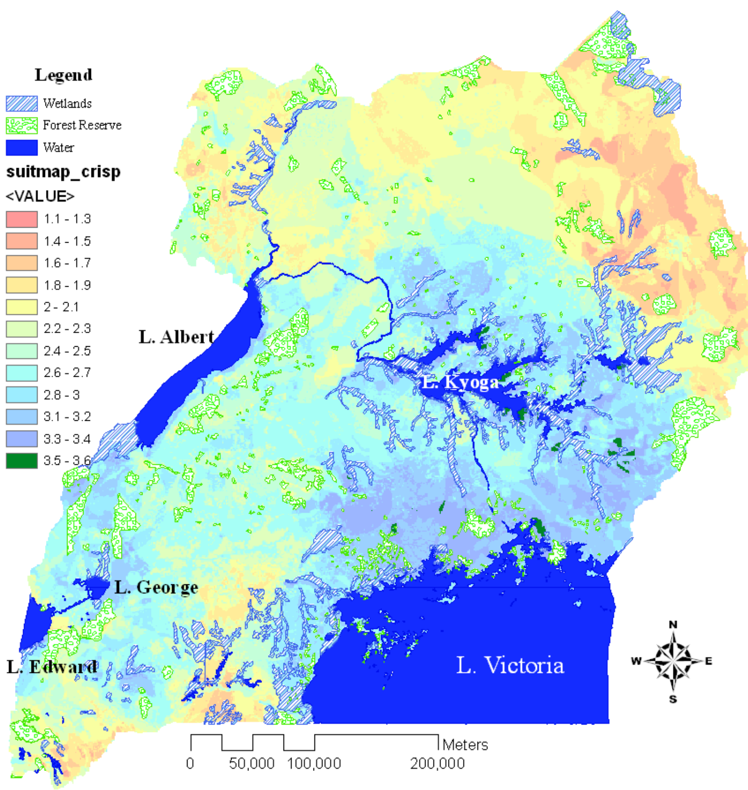

Figure 2. Tilapia and Clarias farming suitability map generated by crisp method

Figure 3: Photos of pond construction site, neighboring wetlands, and agricultural activities

CONCLUSION

There were five major outcomes of the project. These included:

1. Two suitability maps of Uganda for pond based fish farming. The first map was based on crisp classification while the second on fuzzy classification. The maps were developed using a multi criteria evaluation of seven criteria that included water requirement, water temperature, soil texture, slope gradient, potential for farm gate sales, access to local and regional markets, and availability of farm inputs. The site suitability maps designated major wetlands as protected sites that should not be considered for pond based fish farming.
2. A two day workshop was held at the host institution (Makerere University, Uganda) that brought together the major stakeholders (researchers from local institution, fish farmers, and U.S. lead advisors). The first day focused on the state of aquaculture, water availability, pond construction challenges, and use of GIS in site selection. The second day focused on use of an excel spreadsheet tool for proper design and planning for levee and watershed based pond.
3. A 60 m × 80 m pond has been constructed at the selected site for demonstration purposes and for future educational purposes and information dissemination. The site is close to an education facility Makerere University uses to retool national extension workers.
4. Visited two farmer groups in Gulu (Uganda) that work with Gulu University to support orphans through fish farming. This region of the country has been devastated with 20 years of war and with the return of peace, fish farming is one of the activities that have been embraced by the local populace. Discussions centered on possible future collaborations between Gulu University, Makerere University, and the U.S. institutions.
5. A paper has been submitted to a peer reviewed Journal of Applied Aquaculture for publication.

ACKNOWLEDGEMENT

We thank the AquaFISH CRSP for funding the project and EPA P3 for additional funding that enabled for the construction of pilot pond. We also wish to thank Dr. Nelly Isyagi, Maurice Ssebisubi, and John Walakira for the fish pond survey data.

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Improved Cages for Fish Culture Commercialization in Deep Water Lakes

Watershed and Integrated Coastal Zone Management/Experiment/09WIZ03UM

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ABSTRACT

This study assessed the impacts of improved freshwater aquaculture cages designed to reduce waste loadings into Longtan Reservoir in southern Guizhou Province, China. These experimental cages featured a sediment collector under the cages, which allowed for removal of feces and waste feed from the water column. The cages were stocked with catfish and also featured an outer cage stocked with bighead carp, common carp, and tilapia that could feed off plankton and waste feed in the water column and could improve water quality around the cages. The experiment began in May 2010, and data collection continued until December 2010. Fish weight and length were measured monthly to establish growth rates. Fish carcasses, feces, and fish feed were analyzed to determine the percent phosphorus. The sedimentation rates were also measured by sampling the sediment from the sediment collector. Water chemistry data was also collected: NO_3, NO_2, TN, TP, TSS, pH, Chl-a, NH_4, temperature, and Secchi depth. Phytoplankton and zooplankton were also monitored in Longtan Reservoir. Water samples were collected inside each cage and 1m outside the cages at depths of 0.5, 5, and 15m. Additional samples were collected 1km upstream and downstream of the cages, as well as in the bay in which the cages were located.

Contrary to expectations, growth rates of catfish were lower in traditional cages than in modified cages. Feed conversion ratios ranged from 1.37-2.61, but were not statistically different between traditional, modified-a, and modified-b groups. Slower growth rates resulted in lower catfish production from traditional cages. As expected fish in the control cage grew slower than fish in the modified outer cages. Results from the mass balance model indicated that the outer cages retained 0.05-0.07 kg P ton^{-1} fish produced and there was no difference in retention between the modified-a and modified-b cages. This retention was smaller than expected, equaling 0.034-0.05% of the total phosphorus input into the system. ANOVA analysis of model outputs only found a difference in P retained in catfish between traditional and modified cages.

There were no significant differences between the surface and bottom water quality in cages. Water temperature ranged from 19.5 to 30.7℃, pH from 7.99 to 8.80, and DO from 4.76 to 8.71 mg/L from June to December 2010. Ammonia and nitrite accounted for a small proportion of the total inorganic nitrogen,

while nitrate accounted for not only the main part of TIN, but also a major component of total nitrogen. During the growth period, 2.7t dry weight of waste was collected, which inhibited water eutrophication. The feces collected contained 2.93% crude protein, 0.29%TP, and 0.47% TN. There were no significant differences among water quality of traditional or experimental cages. Longtan Reservoir was phosphorus limited, although the content of chlorophyll a showed a significantly positive correlation with TN. There were no significant differences in TN and TP between water from experimental cages and the reservoir.

There were 122 species of phytoplankton, which belonged to 49 genera and 7 phyla. The most dominant species of phytoplankton in the reservoir were *Cyclotella comensis*, *Cyclotella stelligera*, *Navicula exigua*, *Scendesmus bjjuga*, *Trionema minus*, *Merismopedia tenuissima*, *Crptomonas ovate*, *Chlorella minimum*, *Crucigenia rectangularis*. Also there were 92 species of zooplankton including 26 Protozoans, 43 Rotifers, 14 Cladocerans and 9 Copepods. The predominant species were mainly *Keratella cochlearis*, *Brachionus falcatus*, *Dicranophorus caudatus*, *Bosmina coregoni*, and *Paracyclops fimbriatus*. Plankton collections revealed no evidence of the cage system causing a change in the plankton community.

INTRODUCTION

Aquaculture presents reservoir managers and fish farmers with a dilemma. How can production be maximized while maintaining water quality for human use and ecological integrity? An aquaculture system only retains ~ 24% carbon, 31% nitrogen, and 31% phosphorus inputs within the fish biomass, the rest is released into the water column (Troell and Norberg, 1998). In aquaculture, water quality degradation primarily occurs from poorly designed cages, overcapacity of cages, or improper feeding strategies, which highlights the importance of understanding the water body's assimilation capacity (Wu et al., 2000; Guo et al., 2009). When cages produce an excess of uneaten food or feces, nutrient levels around the cages increase and benthic habitats are disturbed, altering ecological relationships in the reservoir (Bureau and Hua, 2010).

Solid waste from cage aquaculture affects the benthic habitat below the cages (Kalantzi and Karakassis, 2006). High organic content in aquaculture wastes enriches benthic sediments and can elevate benthic biomass however; aquaculture enrichment also consistently reduces benthic biodiversity (Mente et al., 2006; Rooney and Podemski, 2009). Diversity decreases due to deoxygenation as organic material decomposes (Kalantzi and Karakassis, 2006; Giles 2008; Rooney and Podemski, 2009). Mitigating benthic degradation usually involves ceasing production over an area to allow the benthic community to rehabilitate or mechanical sediment removal or oxygenation (Angel et al., 2005; Buryniuk et al., 2006). These methods results in decreased farm production and additional management costs.

Phosphorus generally limits phytoplankton biomass in temperate freshwater lakes (Schindler et al., 1978; Bureau and Hua, 2010). However, tropical systems exhibit a more variable relationship between total phosphorus and chlorophyll-a levels (Huszar et al., 2006). If nutrient levels, especially phosphorus, surpass certain thresholds then phytoplankton blooms can have detrimental effects on the water column leading to hypoxic conditions in the hypolimnion, fish kills, reduced water clarity, and cyanobacteria blooms that degrade the taste of fish (Buyukates et al., 2000) and reduce nutritional quality (Mares et al., 2009). Therefore, nutrients released from cage aquaculture into the environment must be kept below thresholds prone to induce negative biological events. Dilution has long been the human solution to nutrification of waters, but in many areas increased anthropogenic nutrient loading has exceeded the assimilative capacities of freshwater systems (Halwart et al., 2007; Troell et al., 2009). How can aquaculture systems be engineered to profitably culture fish while reducing their ecological footprint? Polyculture, long practiced in aquaculture, offers a potential solution. Earliest aquaculture systems in China involved culturing organisms at different trophic levels to manage waste products, for example raising fish in conjunction with rice paddies (Beveridge and Little, 2002). Most polyculture systems are pond based and relatively little research has been done on freshwater cage polyculture.

This experiment assessed the implementation of a polyculture freshwater cage system. A new cage design with two modifications was tested for reductions in waste releases compared to traditional cage designs. The first modification involved a sediment collection cone underneath the cage to capture particulate waste feed and feces. The second modification was an outer cage to hold filter feeding fish which were stocked and not fed. The objectives of this study were to determine the effectiveness of the new cage design by quantifying nutrient releases from modified and traditional cages. This was done by: 1) evaluating growth rates of fish in the inner and outer cages, 2) using a mass balance model to quantify phosphorus dynamics of both types of cages, 3) collecting water samples to assess any changes in water chemistry between the modified and traditional cages and the reservoir, and 4) to quantify plankton populations in the reservoir to evaluate effects of cages on the reservoir.

MATERIALS AND METHODS

Cages for this experiment were situated in Longtan Reservoir on the Hongshui River in southwestern China. The reservoir straddles southern Guizhou province and northern Guangxi province. With a surface area of 360-540 km^2 and a depth at the facility that surpassed 50m, Longtan is characterized as a narrow and deep reservoir surrounded by a karst landscape. During the testing period, water temperature was 19-31 C, pH was generally above 8, and DO was higher than 5 mg/L.

The facility used for our experiment had approximately 50 cages of which 10 were dedicated to the experiment: 6 modified cages divided into 2 sets of 3. Modified-a cages contain an outer cage and no sediment trap while modified-b cages contain both an outer cage and sediment trap. In addition to modified cages were 3 traditional cages, and 1 control cage. Modified cages were 12x12 m in surface area and 6m deep, not including the sediment collector below. The traditional cages were 5x5 m in surface area and 5 m deep, and the control cage was 3x3 m in surface area and 3 m deep.

On 24 May 2010 channel catfish (*Ictalurus punctatus*) were stocked in inner modified cages and traditional cages at a density of 160 fish m^{-2}, equaling 16,000 fish in modified cages and 4,000 catfish in traditional cages. Modified outer cages were stocked with 350 kg of bighead carp (*Hypophthalmichthys nobilis*), 100 kg of Nile tilapia (*Oreochromis nilocticus*), and 50 kg of common carp (*Cyprinus carpio*); this equates to a total density of 11.36 kg m^{-2}. Twice a day (07:30 and 19:30) fish in the inner cages were fed by hand with Tongwei Company Feed. Outer cage and control fish were not fed at all, but left to consume waste drifting out of inner cages as well as natural food in the water column.

To test the efficacy of outer cages in removing effluent waste, an additional control cage was used to determine growth rates of fish supplied with only natural food. This control cage was stocked with 42 kg of bighead carp, 24 kg of tilapia, and 6 kg of common carp for a total density of 8 kg m^{-2}, slightly less than the density of modified outer cages. The cage was situated adjacent to a facility building approximately 10 m away from all cages. To estimate growth rates each fish was weighed at stocking and a sample of 44 fish from this cage sampled on 27 December 2010 and wet weight measured. Average individual wet weight at stocking for bighead carp equaled 312±96g, tilapia 339±98g, and common carp 466±80g. Fish were removed from the cages five times when they were anesthetized, measured for wet weight and total length, and returned to the cage.

Proximate composition, including moisture, crude protein, crude fat, phosphorus, crude fiber, amino acids and crude ash were measured in the feed and fish carcasses. Crude protein and phosphorus in the feces were also determined. Dry matter was measured by weight after drying at 105°C. Crude protein was measured by Kjeldahl method, fat content by Soxhlet method with ether extraction, ash by combustion at 550°C in a muffle furnace, crude fiber by filtration, and amino acid by automatic analyzer. All of the methods were according to Chinese standard methods (GB/T 9695.4 Standardization Administration of the People's Republic of China, 2009).

A number of performance indicators were calculated for the fish, including:

Daily Growth Rate (DGR) = $\Delta W \times 100 / [(t_2 - t_1) \times W_1]$

Specific Growth Rate (SGR) = $[(LnW_2 - LnW_1) \times 100] / (t_2 - t_1)$

Fatness (Kcp) = $100 \times W/L^3$

Feed Conversion Rate (FCR) = $W_F / (\Delta W \times \%\ \text{Survival})$

Nutrient Utilization Rate (PNV) = $G_{nutrition} / C_{nutrition} \times 100$

Weight increment of catfish = $[W_f \times (N \times \%\text{Survival})] - (W_i \times N)$

Crude fiber = $100 - [100 \times F_1 \times N_2/(N_1 \times F_2)]$

where W_1 and W_2 represent weight of fish at t_1 and t_2; W_F the feeding amount during a time period; ΔW the increased weight of fish during the time period; W_i and W_f body weight of fish at stocking and harvest; N number of catfish in the cage; V volume of inner cage, $G_{nutrition}$ and $C_{nutrition}$ growth nutrients, including protein, fat, phosphorus, nitrogen free extract and amino acid.

We also estimated crude digestibility of N and P using the formula:

Apparent Crude Digestibility (%) = $100 - [(100 \times F_1 \times N_2)/(N_1 \times F_2)]$ for either N or P

where F_1 represents percentage of crude fiber in feed, F_2 crude fiber in feces; N_1 percent nitrogen or phosphorus in feed; and N_2 percent nitrogen or phosphorus in feces.

A mass balance model was used to quantify phosphorus dynamics of traditional and modified cages and to estimate differences in phosphorus loadings to the reservoir for each design. Phosphorus discharged from cages into the water column was modeled by the following equation:

$(P_{waste} + P_{feces} + P_{excretion}) = P_{feed} - P_{carcass}$

P_{waste} = Mass of phosphorus in uneaten food (g)

P_{feces} = Mass of indigestable phosphorus egested as feces (g)

$P_{excretion}$ = Mass of excreted soluble phosphorus (g)

P_{feed} = Mass of phosphorus in fish feed (g)

$P_{carcass}$ = Mass of phosphorus retained by fish (g)

The model used a number of equations to determine these parameters, derived from Reid and Moccia (2007).

To corroborate the mass balance model, water samples were also taken around the facility to assess if there was a reduction in phosphorus around the modified cages. Water samples were taken 1 m outside each modified and traditional cage at depths of 0.5, 5, and 15 m. Samples were also taken inside each traditional cage at 0.5 m deep, and inside each modified cage at 0.5 and 5 m deep. An additional 3 samples were also taken approximately 1-2 km away from the cages to establish background reservoir water characteristics independent of any experimental influences. Samples were taken at three depths at 0.5, 5, and 15 m. Water samples were processed at Guizhou Normal University for total phosphorus (TP), chlorophyll *a* (chla), and total nitrogen (TN). TN and TP were determined with persulfate digestion in an autoclave, and concentrations measured colorimetrically (Chinese standard methods of water quality analysis, GB3838-2002). Chla samples were filtered through a 0.45µm glass fiber paper, then the filter was steeped in 90% acetone for 24 hours and chla concentration determined by spectrophotometer (Lin et al., 2005).

Additionally, phytoplankton and zooplankton samples were collected in cages and also at the outside locations where water quality samples were taken. Samples were collected every two weeks between 15 July and 15 November 2010. All collections began at 08:00 and finished before 12:00 the same day. Samples were vertical tows from 5 m to the surface, with a mesh size of 157 µ for phytoplankton and 78 µ for zooplankton. Samples were then preserved for examination in the lab, where they were enumerated to species and estimates of numbers, biomass, and species diversity were made. Species diversity was evaluated using the Shannon-Wiener Index.

Due to seasonal changes in water chemistry, some variables violated the assumption that all data came from an identical distribution, so statistical tests for water quality data were done using a sign test to assess difference in means. Nutrient concentrations inside and outside cages were subtracted from one another, and then sign test used to determine if the difference was significantly greater or lesser than zero. One-way analysis of variance (ANOVA) tests were conducted on final estimates from the mass balance model as well as fish growth data. When significant differences were detected, Tukey HSD test was used to establish which groups were significantly different from each other. All statistics were computed on *R: A Language and Environment for Statistical Computing* (R Development Core Team, 2011). For statistical tests alpha was set at 0.05.

RESULTS

Contrary to expectations, growth rates of catfish were different between traditional and modified cages (Table 1). Even though there was no difference in the feed available between the traditional, modified-a, and modified-b cages, fish in the traditional cages were smaller at harvest (Table 2) than fish in the modified cages. Feed conversion ratios (FCR) ranged from 1.37-2.61 but were not statistically different between traditional, modified-a, and modified-b groups. Slower growth rates resulted in lower catfish production from traditional cages.

As expected fish in the control cage grew slower than fish in the modified outer cages (Figure 1). The average weight of tilapia and bighead carp on 27 December in the outer cages was 702 and 424 g, respectively, while in the control cage the weight was 339 and 304 g, respectively. Common carp were not sampled in the outer or control cages on 27 December and without FBW estimates were not included in growth analysis.

Taking fibrin as an indigestible indicator, apparent digestibility of nitrogen and phosphorous was not significantly different in the two types of modified cages ($P>0.05$). The apparent digestibility of nitrogen and phosphorous in Modified-a cages was 92.5%±0.2% and 79.5±1.0% respectively, while the apparent digestibility of nitrogen and phosphorous in Modified-b cages was 91.2%±0.6% and 82.1%±2.5%, respectively (Table 3). On 1 September, the amount of dry matter and nitrogen collected from the sedimentation cone accounted for 18.8% and 6.5% of the feed applied, respectively (Table 4). On 7 November 7, it represented 21.8% and 16.2% of the feed applied, respectively.

Results from the mass balance model (Table 5) indicate that the outer cages retained 0.05-0.07 kg P ton^{-1} fish produced and there was no difference in retention between the modified-a and modified-b cages. This retention was smaller than expected, equaling 0.034- 0.05% of the total phosphorus input into the system (Table 6). ANOVA analysis of model outputs only found a difference in P retained in catfish between traditional and modified cages.

Contrary to expectations, water quality measurements showed no depression of TP, TN, and chla concentrations inside or outside the modified cages. Water quality measurements showed no statistical difference when measured at 0.5m and 5m and so these data were pooled to create a larger sample size. Once pooled, TP, TN, and chla concentrations were the same inside and outside the cages for both the traditional, modified-a, and modified-b cages (Figure 2). Additionally, samples were also the same between inside, outside, and reference sites for all cages. This indicates that TP, TN, and chla were not elevated near the aquaculture facility.

There were 122 species of phytoplankton collected, belonging to 49 genera and 7 phyla. Altogether, 23 genera and 56 species of Chlorophyta, 10 genera and 37 species of Bacillariophyta, 8 genera and 18 species of Cyanophyta, 2 genera and 4 species of Cryptophyta, 2 genera and 3 species of Euglenophyta, 2 genera and 2 species of Pyrrophyta, and 2 genera and 2 species of Xanthophyta were identified. Phytoplankton in the three types of cages and the control water were mainly composed of Chlorophyta, Bacillariophyta and Cyanophyta, which were typical phytoplankton species found in freshwater lakes and reservoirs. Traditional cages had greater number of species than modified a or b cages, and all cages had more species than reservoir samples. However, biomass of phytoplankton was fairly similar between the 3 cage types, with traditional cages ranging from 0.35-2.98 mg/L and an average of 1.47 mg/L; modified b cages ranging from 0.47-2.47 mg/L and averaging 1.36 mg/L; and modified a ranging from 0.38-2.19 mg/L, averaging 1.44 mg/L.

The dominant species of phytoplankton changed over time (Table 7). *Cyclotella comensis* was dominant mostly in mid-July, *Cyclotella stelligera* from mid-July to mid-November, *Navicula exigua* in mid-July and mid-September, *Scenedesmus bijuga* and *Tribonema minus* from mid-July to mid-August, *Merismopedia tenuissima* appeared in late August, *Cryptomonas rostrata* from mid-October to mid-November, both *Tetraedron minimum* and *Crucigenia quadrata* were most abundant in mid-November. Phytoplankton biomass also increased as water temperature increased. For example, the phytoplankton biomass in traditional cages was 2.98 mg/L in mid-July and only 0.35 mg/L in mid-November. The Shannon-Wiener index H′ for traditional cages averaged 2.15, for modified b cages it averaged 2.10, and for modified a cages it averaged 2.06. Overall the cages showed slightly elevated phytoplankton populations compared to open water, and no differences among cage type.

There were 92 species of zooplankton identified including 26 species of Protozoa, 43 of Rotifera, 14 of Cladocera and 9 of Copepoda. Rotifera were most abundant, and Copepoda least. Dominant species included *Keratella cochlearis*, *Brachionus falcatus*, *Brachionus forficula, Keratella valga*, *Dicranophorus caudatus*, *Brachionus donneri*, *Bosmina coregoni* and *Paracyclops fimbriatus*. Once again, biomass trends in the 3 cage types were similar (Table 8), and densities of zooplankton were also fairly similar among cage types. Zooplankton density ranged from 48-678 ind./L in traditional cages and averaged 287 ind./L, modified b cages ranged from 41-570 ind./L and averaged 176 ind./L, while modified a cages ranged from 40-490 ind./L and averaged 239 ind./L. For all cage types, density was maximum in mid-September and minimum in mid November. The Shannon-Weaver index H′ for traditional cages averaged 1.78, while modified b and a cages both averaged 1.74. Once again for zooplankton, populations inside cages were slightly elevated above background reservoir levels, and did not differ largely among cage types.

The net income ratio of modified cages a and b were 74.3% and 73.8%, respectively. Cost of the waste collection device accounted for only 0.6% of the total cost. The revenue of channel catfish in modified cages a and b accounted for 96.8% and 96.4% of the total revenue, respectively. The revenue of fish in the outer cages of modified cages a and b accounted for 3.2% and 3.6% of the total revenue, respectively.

DISCUSSION

This study tested the efficacy of planktivorous fish to retain nutrients from cage aquaculture. Fish in outer cages retained <1% of total phosphorus input from cages. This retention was not enough to influence nutrient concentrations between modified, traditional, and reference sites. This raises questions about the availability of waste nutrients from intensively fed cages to consumption of materials by filter feeding fish. Since fish in outer cages grew faster than fish in the control cage, they must have had access to feed energy drifting out of the inner cage, which elevated their growth rates. However, they may not have had access to elevated plankton populations because plankton populations were only slightly elevated in cages compared to open water. Some studies have shown elevated production near aquaculture facilities (Angel, 2002; Spanier et al., 2003; MacDonald et al., 2011), and other authors have found no increase in productivity around cages (e.g., Navarette-Mier et al., 2010). In our case, the waste feed appeared to increase fish growth near the facility, but there was no major increase in natural foods there.

The growth of channel catfish demonstrated obvious seasonal changes, which were related to the changes in water temperature and possibly DO. Compared with other cage culture experiments on channel catfish, this experiment had higher yield per unit time and unit volume of the cage (Ding et al., 1999; Qu and Du, 2002; Zhu et al., 2004; Kelimo et al., 2005; He and Pei, 2007).

Total phosphorus input into the system was not unusually high. Phosphorus loading at Longtan was actually less than the 25-35 kg P ton^{-1} fish that Guo and Li (2003) and Guo et al. (2009) reported in previous studies on cage aquaculture. Guo and Li's (2003) larger waste output can be explained by an imprecise feeding regime for cultured fish in that study, consisting of forage fish, grass, and formulated feed. Using nutritionally imprecise feeding can increase phosphorus loading from aquaculture (Cho et al., 1994, Cho and Bureau, 2001; Bureau and Hua, 2010). De Silva et al. (2010) supported this conclusion by finding that waste from artisanal feeds loaded more phosphorus than waste from commercial feeds. The high ratio of intensively fed fish to filter feeding fish (11.4:1), in this study may have resulted in lower phosphorus retention rates than other studies have shown. Yi et al. (2003) cited a range of phosphorus retention values from 0.86-17% by filter feeding fish in integrated pond systems. The stocking ratios of intensively fed to filter feeding fish ranged from 2.5:1-9:1 in that study, and lower ratios achieved higher retention. In partitioned aquaculture systems a ratio of catfish to tilapia stocking of 4:1 was found to be optimal to control algae growth (Brune et al., 2003). The high ratio in our study probably reduced retention capacity. Future research on optimal stocking ratios in reservoir systems may improve nutrient retention.

Herbivorous and filter feeding finfish may retain <10% of P in reservoir systems. This presents a challenge to freshwater integrated aquaculture since marketable aquatic autotrophs are limited; the lack of marketable freshwater autotrophs may limit the maximum nutrient retention possibilities for freshwater integrated aquaculture.

Constraints in sampling ability and methodological assumptions limited conclusions drawn from the results. The remote location of the facility made sampling infrequent, and the experiment occurred at a commercial facility so it is unknown how the proximity of the experiment to other cages at the facility confounded results. Since sampling only occurred on one location outside of the cages, water flow could influence the results of the water chemistry. Flow appeared negligible, but if physical processes were moving nutrient loads from the cages away from our sampling site then we would under estimate cage loading of nutrients. Other studies have shown cage aquaculture impacts extending up to 50m from cages (Guo and Li, 2003). Finally, low stocking density made sampling outer cage fish very difficult, resulting in small samples sizes.

Most integrated aquaculture research occurs in ponds and marine systems, many of these experiments have successfully increased trophic efficiency (Yi et al., 2003; Angel et al., 2002; Troell et al., 2009; MacDonald et al., 2011), though some integrated cage mariculture publications find no enhanced growth from integrated organisms (Navarett-Mier et al., 2010). The elevated growth rate of fish in outer cages suggests that productivity around cages increased, but the mechanisms and magnitude of this increase were not clear. The assumption that ecological productivity is elevated in the vicinity of the cages must also be tested.

According to the analysis on economic benefits, the cost of the solid waste collection device only accounted for 0.6% of the total cost, quite a low proportion, and it could effectively reduce the environmental pollution of cage culture. The costs of fish fry and feed constituted the main part of total cost, and this proportion was up to 95%. The revenue from channel catfish was the main contributor to total revenue. The revenue from fish cultured in the outer cage accounted for only a small proportion of the total revenue.

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Table 1. Growth performance and production results for each cage type. Capital letter superscripts indicate a significant difference between averaged cage values in each column (p>0.05).

Cages	Feed Applied (g/fish)	FBW (g)	Growth Rate (g/day)	Tons Produced (ton=1000kg)	FCR
Trad1	1251	579.8	2.2	2.32	2.61
Trad2	1251	581.8	2.2	2.33	2.60
Trad3	1251	580.9	2.2	2.32	2.60
Avg.	**1251.00**	**580.8^{A}**	**2.2^{A}**	**2.32^{A}**	**2.60**
Mod-a1	1375	810.4	3.3	12.97	1.94
Mod-a2	2030	886.6	3.6	14.19	2.58
Mod-a3	1789	963.1	4.0	15.41	2.07
Avg.	**1731.33**	**886.7^{B}**	**3.6^{B}**	**14.19^{B}**	**2.20**
Mod-b1	1375	1106.3	4.6	17.70	1.37
Mod-b2	2030	1042.3	4.3	16.68	2.15
Mod-b3	1789	861.7	3.5	13.79	2.35
Avg.	**1731.33**	**1003.5^{B}**	**4.2^{B}**	**16.06^{B}**	**1.96**

Table 2. Average weight (grams), one standard deviation, and sample size for all fish species at each sampling event. Different capital superscripts denote a significant difference.

Date	a.catfish	± SD	*n*	b.catfish	± SD	*n*	Trad. catfish	± SD	*n*
16-Jul-10	154.67	61.60	94	151.57	83.93	75	154.52	103.89	70
30-Jul-10	238.44	78.03	74	154.23	61.68	63	189.47	80.81	102
30-Sep-10	542.13	142.78	60	588.20	164.67	60	487.02	149.91	60
7-Nov-10	718.57	171.09	60	801.45	216.45	60	583.53	147.21	60
27-Dec-10	886.70^{A}	258.90	104	1000.62^{A}	653.76	60	580.85^{B}	216.19	63
Date	**a.bighead**	**± SD**	***n***	**b.bighead**	**± SD**	***n***			
27-Dec-10	424.91	151.21	32	522.50	211.73	22			
Date	**a.tilapia**	**± SD**	***n***	**b.tilapia**	**± SD**	***n***			
27-Dec-10	734.47	370.43	17	679.85	149.33	27			

Table 3. Conversion ratios of nutrients in different experimental cages.

Cage	Protein (%)	Fat (%)	Phosphorous (%)	Essential amino acid (%)
Modified a	31.06	65.79	51.02	62.89
Modified b	34.36	60.61	36.10	54.64

Table 4. The ratio of collection of dry matter and nitrogen (mean ± SE) in material collected from the sedimentation cone.

Date	Dry matter		Nitrogen	
	Feed (kg)	Collected amount (kg)	Feed (g)	Collected amount (g)
9.1	108.5	20.3±1.8	5936.3	384.1±48.2
11.7	94.4	20.6±1.2	4944.2	800.4±96.1

Means with different superscripts within the same column indicate significantly different ($P < 0.05$).

Table 5. Mass balance model outputs. Capital letter superscripts indicate a significant difference between averaged cage values in each column (p>0.05).

Cages	Total P Input (kg / ton)	P Retained in Catfish (kg / ton)	Total Waste (kg / ton)	Particulate Waste (kg / ton)	Soluble Waste (kg / ton)	P Retained in Outer Cage (kg / ton)	Unaccounted (kg / ton)
Avg. Trad	**17.02**	**4.30^{A}**	**12.81**	**6.21**	**6.16**	**N/A**	**-0.10**
Trad1	17.04	4.30	12.84	6.22	6.18	N/A	-0.10
Trad2	16.99	4.31	12.78	6.20	6.15	N/A	-0.10
Trad3	17.01	4.30	12.81	6.21	6.16	N/A	-0.10
Avg. Mod-a	**15.39**	**4.61^{B}**	**10.94**	**5.61**	**4.86**	**0.06**	**0.31**
Mod-a1	13.40	4.56	9.04	4.89	3.69	0.07	0.27
Mod-a2	18.09	4.61	13.58	6.60	6.52	0.06	0.36
Mod-a3	14.67	4.66	10.19	5.35	4.37	0.06	0.29
Avg. Mod-b	**13.87**	**4.68^{B}**	**9.39**	**5.06**	**3.86**	**0.05**	**0.28**
Mod-b1	9.82	4.73	5.37	3.58	1.31	0.05	0.20
Mod-b2	15.39	4.70	10.85	5.61	4.77	0.05	0.31
Mod-b3	16.40	4.60	11.94	5.98	5.49	0.06	0.33

Table 6. Fate of phosphorus expressed as a percent of total P introduced into the system from feed. See Table 4 for definition of categories.

	P Retained in Catfish	Total Waste P	Particulate Waste P	Soluble Waste P	P Retained in Outer Cage
Avg. Trad	**25.30%**	**72.70%**	**36.47%**	**36.23%**	N/A
Trad1	25.25%	72.75%	36.47%	36.28%	N/A
Trad2	25.35%	72.65%	36.47%	36.18%	N/A
Trad3	25.30%	72.70%	36.47%	36.23%	N/A
Avg. Mod-a	**30.42%**	**67.58%**	**36.47%**	**31.11%**	**0.41%**
Mod-a1	34.01%	63.99%	36.47%	27.52%	0.50%
Mod-a2	25.51%	72.49%	36.47%	36.02%	0.34%
Mod-a3	31.76%	66.24%	36.47%	29.77%	0.38%
Avg. Mod-b	**35.59%**	**62.41%**	**36.47%**	**25.94%**	**0.41%**
Mod-b1	48.18%	49.82%	36.47%	13.35%	0.50%
Mod-b2	30.56%	67.44%	36.47%	30.97%	0.34%
Mod-b3	28.03%	69.97%	36.47%	33.50%	0.38%

Table 7. Dominant species of phytoplankton in each cage type, in water near each cage type, and in open reservoir water in Longtan Reservoir during 2010.

mid-July	Trad. cages	*Cyclotella comensis*	*Navicula exigua*	*Tribonema minus*
	Outside Trad.	*Cyclotella comensis*	*Navicula exigua*	*Cyclotella stelligera*
	Mod. b	*Cyclotella comensis*	*Navicula exigua*	*Cyclotella stelligera*
	Outside b	*Cyclotella comensis*	*Navicula exigua*	*Tribonema minus*
	Mod. a	*Cyclotella comensis*	*Cyclotella stelligera*	*Navicula exigua*
	Outside c	*Cyclotella comensis*	*Navicula exigua*	*Cyclotella stelligera*
	Open water	*Cyclotella comensis*	*Cyclotella stelligera*	*Navicula exigua*
late July	Trad. cages	*Cyclotella stelligera*	*Scenedesmus bijuga*	*Tribonema minus*
	Outside Trad.	*Cyclotella stelligera*	*Tribonema minus*	*Cyclotella comensis*
	Mod. b	*Cyclotella stelligera*	*Tribonema minus*	*Cyclotella comensis*
	Outside b	*Cyclotella stelligera*	*Tribonema minus*	*Cyclotella comensis*
	Mod. a	*Cyclotella stelligera*	*Tribonema minus*	*Scenedesmus bijuga*
	Outside c	*Cyclotella stelligera*	*Tribonema minus*	*Navicula exigua*
	Open water	*Cyclotella stelligera*	*Scenedesmus bijuga*	*Cyclotella comensis*
mid-August	Trad. cages	*Scenedesmus bijuga*	*Navicula exigua*	*Tribonema minus*
	Outside Trad.	*Cyclotella stelligera*	*Tribonema minus*	*Scenedesmus bijuga*
	Mod. b	*Tribonema minus*	*Scenedesmus bijuga*	*Cyclotella stelligera*
	Outside b	*Tribonema minus*	*Scenedesmus bijuga*	*Navicula exigua*
	Mod. a	*Tribonema minus*	*Navicula exigua*	*Scenedesmus bijuga*
	Outside c	*Tribonema minus*	*Cyclotella stelligera*	*Scenedesmus bijuga*
	Open water	*Tribonema minus*	*Cyclotella stelligera*	*Scenedesmus bijuga*
late August	Trad. cages	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Navicula exigua*
	Outside Trad.	*Cyclotella stelligera*	*Navicula exigua*	*Merismopedia tenuissima*
	Mod. b	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Navicula exigua*
	Outside b	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Navicula exigua*
	Mod. a	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Navicula exigua*
	Outside c	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Cyclotella comensis*
	Open water	*Cyclotella stelligera*	*Merismopedia tenuissima*	*Navicula exigua*
mid-September	Trad. cages	*Cyclotella stelligera*	*Navicula exigua*	*Tribonema minus*
	Outside Trad.	*Cyclotella stelligera*	*Navicula exigua*	*Cryptomonas rostrata*
	Mod. b	*Cyclotella stelligera*	*Navicula exigua*	*Tribonema minus*
	Outside b	*Cyclotella stelligera*	*Navicula exigua*	*Scenedesmus bijuga*
	Mod. a	*Cyclotella stelligera*	*Navicula exigua*	*Tribonema minus*
	Outside c	*Cyclotella stelligera*	*Navicula exigua*	*Scenedesmus bijuga*
	Open water	*Cyclotella stelligera*	*Navicula exigua*	*Tribonema minus*
mid-October	Trad. cages	*Cyclotella stelligera*	*Rhodomonas lacustris*	*Cryptomonas rostrata*
	Outside Trad.	*Rhodomonas lacustris*	*Cyclotella comensis*	*Cyclotella stelligera*
	Mod. b	*Cyclotella stelligera*	*Tribonema minus*	*Cryptomonas rostrata*
	Outside b	*Cyclotella stelligera*	*Cryptomonas rostrata*	*Navicula exigua*
	Mod. a	*Cyclotella stelligera*	*Cryptomonas rostrata*	*Tribonema minus*
	Outside c	*Cyclotella stelligera*	*Cryptomonas rostrata*	*Coelastrum sphaericum*
	Open water	*Cyclotella stelligera*	*Rhodomonas lacustris*	*Cryptomonas rostrata*
mid-November	Trad. cages	*Cryptomonas rostrata*	*Cyclotella stelligera*	*Rhodomonas lacustris*
	Outside Trad.	*Cryptomonas rostrata*	*Cyclotella stelligera*	*Cyclotella meneghiniana*
	Mod. b	*Cryptomonas rostrata*	*Cyclotella stelligera*	*Coelastrum sphaericum*
	Outside b	*Tetraedron minimum*	*Cryptomonas rostrata*	*Cyclotella stelligera*
	Mod. a	*Cryptomonas rostrata*	*Cyclotella stelligera*	*Cyclotella meneghiniana*
	Outside c	*Cryptomonas rostrata*	*Rhodomonas lacustris*	*Crucigenia quadrata*
	Open water	*Cryptomonas rostrata*	*Rhodomonas lacustris*	*Cyclotella meneghiniana*

Table 8. The biomass (mg/L) of zooplankton found in three groups of cages and open reservoir water in Longtan Reservoir during 2010.

	Trad. cages	Outside Trad.	Mod. B cages	Outside B cages	Mod. A cages	Outside A cages	Open Reservoir
mid-July	1.11±0.27	1.55	1.18±0.18	2.06	0.73±0.53	1.04	15.75
late July	4.60±1.64	4.95	4.01±2.80	7.24	2.89±0.28	4.76	7.59
mid-August	2.16±0.53	4.18	2.05±0.81	4.1	1.84±0.37	5.47	8.66
late August	2.88±0.61	1.53	2.64±0.77	0.95	1.65±0.30	2.78	9.86
mid-September	5.94±3.33	6.94	6.10±1.94	4.7	5.05±2.48	13.14	5.7
mid-October	1.40±0.31	1.16	2.11±0.82	0.92	2.28±0.56	2.61	2.25
mid-November	0.40±0.20	0.05	0.33±0.09	1.02	0.64±0.36	0.51	0.75
average	2.64±2.00	2.91±2.48	2.63±1.91	3.00±2.43	2.15±1.50	4.33±4.28	7.22±5.01

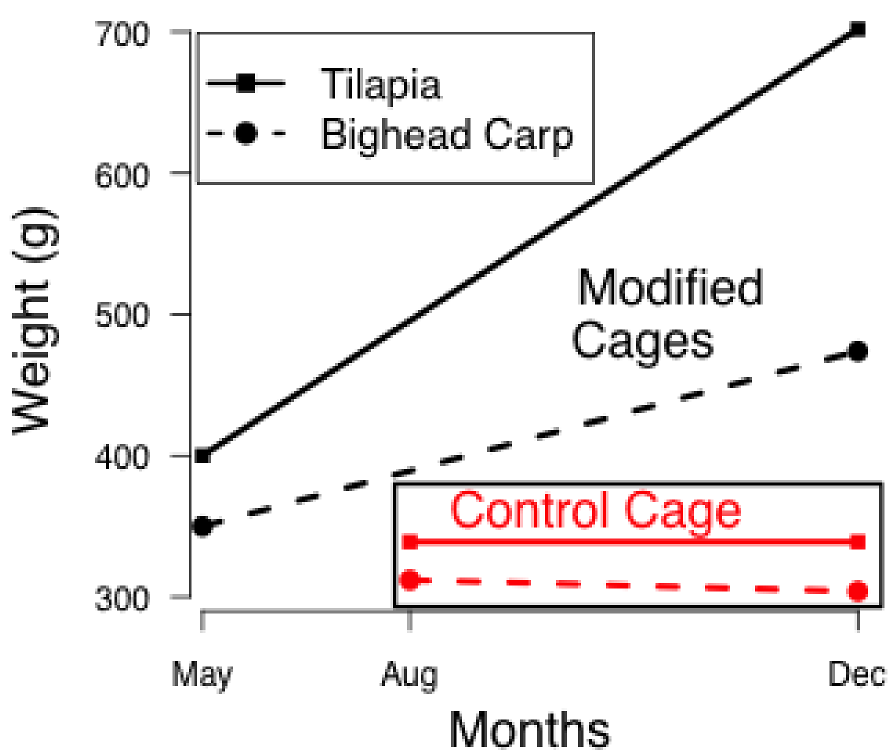

Figure 1. Average weight of carp and tilapia in modified and control cages at stocking and at harvest.

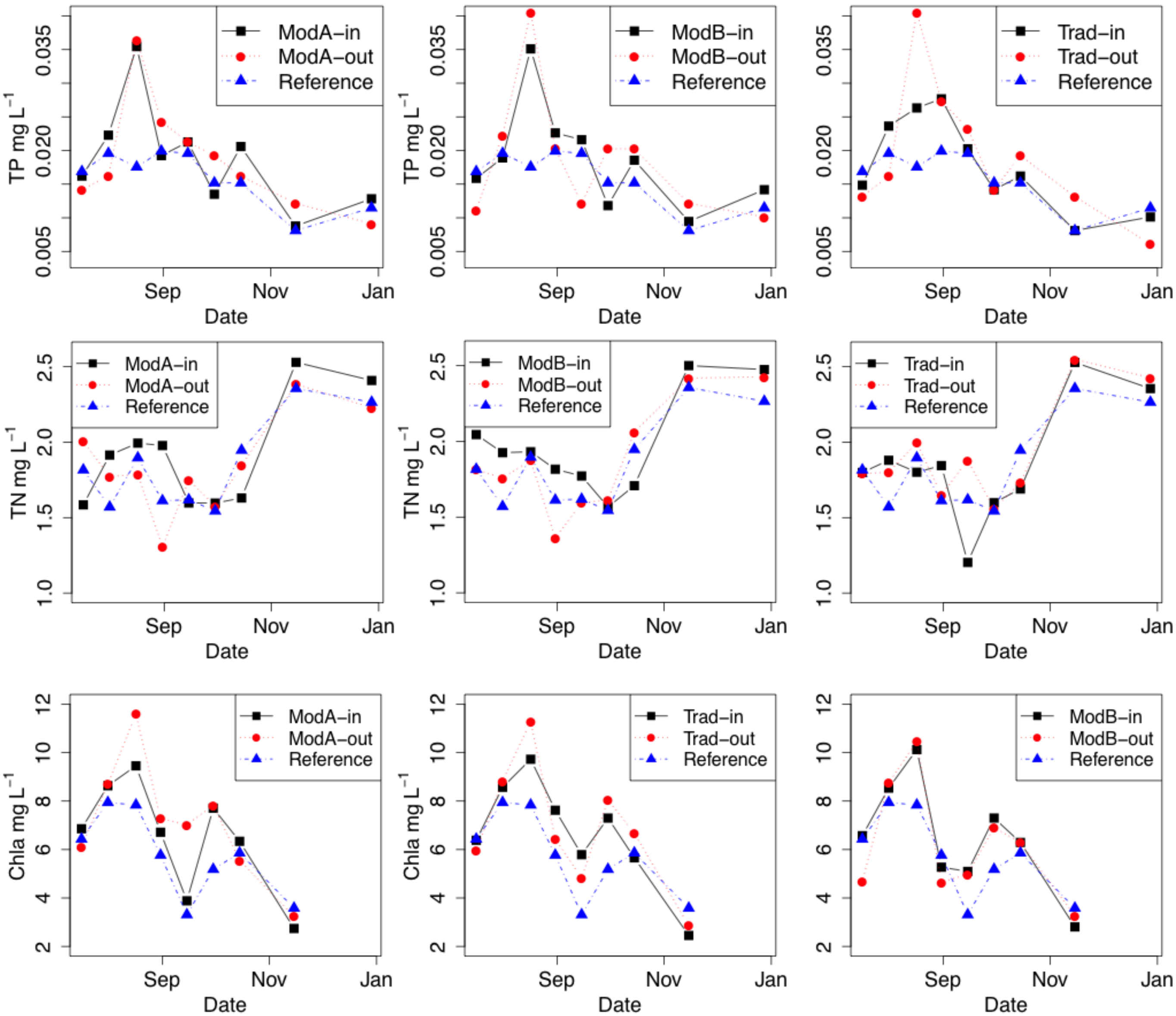

Figure 2. Water quality measurements collected during fish culture inside cages, 1 m outside cages, and at reference sites.

Invasion of the Red Swamp Crayfish (*Procambarus clarkii*) in China: Genetic Analysis of the Invasion and the Impacts Evaluation

Mitigating Negative Environmental Impacts/Study/09MNE01UM

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ABSTRACT

This research was conducted to study the population genetic structure of red swamp crayfish invasion in China, to identify their invasion centers, to explore if populations derived from single or multiple introduction events, and to investigate the impacts of red swamp crayfish invasion in China.

A total of 1776 crayfish sampled from 37 sites (35 sites from China, one site from America and one site from Japan) were obtained to study population genetic structure and dispersal mechanisms of red swamp crayfish. Twelve microsatellites were used in this research. The allele number ranged from three to twenty seven. The overall observed heterozygosity (*Ho*) was 0.6723, the overall gene diversity (*He*) was 0.7913, and the overall polymorphism information content (*PIC*) was 0.7551. The genetic distance (0.145) between population Xuyi-wild (XYw) and population Xuyi-culture (XYc) was lowest, while the genetic distance (0.999) between population Zhongxian (ZX) and population Japan (Jap) was highest. The Nei's genetic identity (0.865) between XYw and XYc was highest while the Nei's genetic identity (0.368) between ZX and Jap was lowest. The NJ tree consisted of two major branches, one branch included the red swamp crayfish populations in America and Japan, the other branch included all populations collected in China. AMOVA revealed that 91.26% of genetic variation could be explained by the variation within populations.

Six haplotypes were found in the partial COI sequence of *P. clarkii* (145 individuals) with a length of 637bp. The haplotype diversity of the partial COI sequence was 0.419, the variance was 0.00188, and the standard deviation was 0.043. The nucleotide composition of all the haplotypes was 40.6% T, 12.7% C, 26.7% A, and 20.0% G. The nucleotide diversity was 0.267%. Twelve parsimony informative sites and three singleton variable sites were detected in the COI sequences. Three haplotypes were found in the 16SrRNA sequence of *P. clarkii* (142 individuals) with a length of 293bp. The haplotype diversity of the 16SrRNA sequence was 0.431, the variance of haplotype diversity was 0.00158, and the standard deviation of haplotype diversity was 0.040. The nucleotide composition of all the haplotypes was 36.5% T, 9.9% C, 34.4% A, and 19.2% G. The nucleotide diversity was 0.172%. Two parsimony informative sites and one base deletion were detected in the 16SrRNA sequences. The positive *Fs* values were obtained from analysis of 16SrRNA (0.953 and P=0.269) and COI (1.859 and P=0.124), which indicated that all red swamp crayfish populations did not experience significant population expansion.

Based on microsatellites and partial mitochondrial DNA data analysis of 37 populations, we speculate that the suburbs of Nanjing, Jiangsu province was the invasion center in China, and crayfish dispersed into Jiangsu province along the Changjiang river. Meanwhile, human-mediated dispersal might have played a role in the expansion and genetic differentiation of this species. Red swamp populations in China probably derived from a single introduction of a large number of individuals from different populations in Japan.

INTRODUCTION

Because of the increased transfer of non-indigenous species (NIS) to new ecosystems and a growing awareness of the potential impacts on recipient ecosystems, studies on biological invasions have increased dramatically over the past 20 years. Recently, much attention has been paid on some aquatic species (LeBlanc et al., 2007; Valentine et al., 2007). The red swamp crayfish (*Procambarus clarkii*), which is native to South central USA and Northeastern Mexico, is one of the most famous invasive species in the world (Huner, 1988; Zhu and Yue, 2008).

Successful invasion requires that a NIS pass through a series of filtering stages that include transport, release, establishment, and, in many cases, dispersal. The red swamp crayfish lacks efficient dispersal capacities such as easily transported resting eggs or highly mobile larval stages. Compared to plants or invertebrate species such as insects or mollusks, the ability of natural dispersal of this species is relatively weak (Geiger et al., 2005). However, anthropogenic activities have played a crucial role in translocation of the red swamp crayfish, and high reproductive output, short development time and flexible feeding habits provide this species a very strong adaptability to various ecosystems.

The red swamp crayfish has become a successful worldwide invader, and in the Mediterranean region it provides a well documented example of the quick expansion of an alien species (Adao and Marques, 1993; Correia and Costa, 1994; Geiger et al., 2005). In 1973, it was introduced to two aquaculture installations located in southwestern Spain (Habsburgo-Lorena, 1983). It has become a widespread species throughout the Mediterranean region and Europe after only for three decades (Adao and Marques, 1993; Correia and Costa, 1994; Stucki and Staub, 1999; Arrignon et al., 1999).

As in Mediterranean region, the invasion status of red swamp crayfish in China is also serious. This crayfish was introduced to Nanjing, China from Japan in 1930s. It is now found in almost all waters including lakes, rivers and even paddyfields in most provinces of China: from Liaoning (northern China) to Guangdong (southern China) and from Taiwan (eastern China) to Sichuan (western China) (Li et al., 2005; Liu et al., 2008).

While less attention is paid to the invasion of this crayfish in China, much effort focuses on technologies of reproduction and breeding (Gong et al., 2008). Crayfish aquaculture has developed rapidly and this species become one of the most important aquatic products in China (Bi et al., 2008). The invasion of red swamp crayfish is a big threat to native crayfish and macrophytes, due to its predatory and grazing activity (Geiger et al., 2005). Red swamp crayfish is an important pest of wet-seeded rice fields (*Oryza sativa*) (Anastacio et al., 2005). As a vector of many diseases, it has a severe impact on preservation and reintroduction of native crayfish (Diéguez-Uribeondo et al., 1995). In addition, it accumulates heavy metals and other pollutants in its organs and body tissues and transmits them to higher trophic levels (Geiger et al., 2005).

The purpose of this study is to evaluate change in population structure of the red swamp crayfish after successful invasion and fast dispersal in China, and to determine impacts of the invasion.

MATERIALS AND METHODS

This study mainly consisted of two components. The first was to study population genetic structure of red swamp crayfish invasion in China, to identify invasion centers and dispersal patterns and to explore whether populations were derived from single or multiple introduction events. The second was to survey impacts of the red swamp crayfish invasion.

Population genetic analysis of red swamp crayfish invasion in China and its ways of dispersal
Our sampling sites covered the major distribution range of red swamp crayfish in China, including one to three sites from each province. Totally, 35 sampling sites were selected from China and one site each from America and Japan (Table 1).

Muscle cuts of 48 individuals were sampled at each site. Samples were stored in the 100% ethanol for DNA extraction. DNA was isolated using ammonium acetate which is now routinely used in our laboratory for preparing DNA. DNA was diluted to a final concentration of 100ng/µL and arrayed on 96-well PCR plates for genotyping of microsatellites.

Twelve microsatellites were used to amplify the DNA solutions. One microsatellite (PCL24) cloned from a partial genomic DNA library enriched for CA- and GA-microsatellites was used; details of genomic library construction and microsatellites cloning were described in Zhu and Yue (2008). An additional eleven microsatellites (PcLG-03, PCLG-04, PcLG-07, PcLG-09, PCLG-10, PCLG-13, PCLG-15, PCLG-17, PcLG-29, PcLG-32, PcLG-48) were selected from Belfiore and May (2000). We performed PCR on an Eppendorf Mastercycler gradient machine in 10μL reaction volumes containing 50 ng DNA, one PCR buffer (TaKaRa) with 1.5 mM $MgCl_2$, 250 nM of each primer, 50 μM of each dNTP and one unit of DNA polymerase (TaKaRa).

Following amplification, each PCR product was mixed with 1μL of sequencing dye. Four microliters of each PCR product were electrophoresed on polyacrylamide gel 8% acrylamide, 650μL of 10% ammonium persulfate, and 65μL of N,N,N_0,N_0-tetramethylethylenediamine (TEMED). Gel fixation and silver staining were performed following the method described by Sambrook et al. (1989). Sizes of alleles were determined according to a marker of puc18 DNA/*MspI* (TIANGEN).

The number of alleles (*A*), the observed heterozygosity (H_O) and the expected heterozygosity (*He*) were determined using the software GENEPOP 4.05.2. The Hardy-Weinberg departure value (*D*) was obtained using the equation, $D = (Ho–He)/He$. The polymorphism information content (*PIC*) was estimated according to the following formula (Botstein et al., 1980):

$$PIC = 1 - \sum_{i=1}^{m} p_i^{\,2} - \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} 2\, p_i^{\,2} p_j^{\,2}$$

where *pi* is the gene frequency of the *i*th allele, *pj* is the gene frequency of the *j*th allele, and m is the allele number.

ARLEQUIN 3.5 was applied for assignments of individuals to populations using a log-likelihood method (Paetkau et al., 1997) and analysis of molecular variance (AMOVA). Ratios of the variance components could then be used to define population structure. Significance was tested by comparing observed values to a null distribution generated by permutation using 10,000 replicates. The bottleneck hypothesis was tested using software BOTTLENECK 1.2.02 (Cornuet and Luikart, 1996) under the infinite allele model (IAM), stepwise mutation model (SMM) and two-phased model of mutation (TPM). Nei's standard genetic distances D_A between all pairs of individuals were estimated to show the phylogenetic relationship among individuals (Nei, 1978). Based on the distance matrix, the software MEGA 5.05 was employed to construct NJ dendrogram.

The genomic DNA of 15 sampling sites (Table 2 and 3) was isolated using ammonium acetate method. The COI gene fragments were amplified using primers LCO 1490 and HCO 2198 from Folmer et al. (1994) under thermocycling conditions. The 16SrRNA gene fragments were amplified with the oligonucleotide primers 1471 and 1472 (Crandall et al., 1995), again under thermocycling conditions. PCR products were directly sent to Invitrogen Biotech (Shanghai) Co., Ltd and Sangon Biotech (Shanghai) Co., Ltd. to sequence. The length of the amplified COI and 16SrRNA fragments were 637 bp and 293bp respectively and could thus be unambiguously aligned by hand.

The variation sites, parsimony informative sites, number of haplotypes, and nucleotide diversity were determined by using the software DnaSP 5.10. The Neutral testing (Fu'*Fs* test) was also considered by DnaSP 5.10. ARLEQUIN v3.5.1.2 was applied for analysis of molecular variance (AMOVA). The genetic distances between populations were calculated by MEGA 5.05 and a NJ dendrogram was constructed.

Survey of impacts of the red swamp crayfish invasion in China

The survey was on crayfish impacts was conducted in Sichuan, Jiangsu, Zhejiang, Anhui, Hubei, Hunan and Jiangxi provinces. A questionnaire was used to estimate the effects on native crayfish and macrophytes, diseases, accumulation of heavy metals, areas of destroyed rice fields and destruction of some water conservation projects caused by the red swamp crayfish. In addition, the internet was another channel to get information about the negative impacts of red swamp crayfish.

RESULTS

Population genetic analysis

Alleles were detected for twelve microsatellite loci over 37 populations (1776 individuals), ranging from a low of three alleles to a high of 27 (Appendix Table 1). The mean frequency of private alleles was 0.03096. The overall observed heterozygosity (*Ho*) was 0.6723, the overall gene diversity (*He*) was 0.7913, and the overall polymorphism information content (*PIC*) was 0.7551. The American and Japanese populations displayed similar and highest genetic diversity (*Na* = 14.5833, *Ne* = 8.8149, *He* = 0.8799 and *PIC* = 0.8579 in American; *Na* = 14.3333, *Ne* = 9.3691, *He* = 0.8873 and *PIC* = 0.8667 in Japanese) among the 37 populations, while ZX population showed the lowest relatively (*Na* = 6.4167, *Ne* = 3.6813, *He* = 0.7002 and *PIC* = 0.6553). Overall, all the red swamp crayfish populations evaluated in China had high genetic diversity (*Na* = 6.4167-11.7500, *Ne* = 3.6813-6.4795, *He* = 0.7002-0.8214 and *PIC* = 0.6553-0.7903) (Table 3). Most loci showed significant deficiency of heterozygosity in almost all populations (Appendix Table 1).

Genetic distance (0.145) between populations XYw and XYc was the lowest, while genetic distance (0.999) between the populations ZX and Japan was the highest (Table 4). The Nei's genetic identity (0.865) between the populations XYw and XYc was highest while the Nei's genetic identity (0.368) between the populations ZX and Jap was lowest (Table 4). The gene flow among populations ranged from a low of 1.284 between DY and PYL population to a high of 10.595 between between XYw and XYc population (Table 5). It can be seen that the gene interchange between XYw and XYc population occurred very frequently and far greater than the gene flow among other populations (range from 1.284 to 6.968). The genetic diversity (*Fst*) in 37 populations of *P. clarkii* ranged from a low of 0.023 between XYw and XYc population to a high of 0.157 between DY and YJ, NX population (Table 5).

The Nei's standard genetic distances for each pair of red swamp crayfish populations (Table 4) was used to construct a neighbor-joining tree based on genetic distances was (Figure 1). The NJ tree consisted of two major branches, which were congruent with regional groupings; one branch included populations collected in America and Japan, the other branch included all red swamp crayfish populations collected in China. The sub-branch, including populations from Baguazhou township, Xiaguan District, Guangfengwei section of Changjiang river, Nantong, and Ningbo, was nearest to the foreign branch. The other sub-branches in the China were not congruent with regional groupings.

AMOVA revealed that 91.26% of genetic variation could be explained by the variation within populations, while the remaining 8.74% came from variation among populations (Table 6).

IAM, TPM, and SMM were applied to test if microsatellites displayed a departure from the mutation-drift equilibrium. Under IAM, the Sign tests revealed that 32 sites may have experienced a bottleneck ($P<0.05$), while Wilcoxon's signed rank tests detected that all 37 populations may have experienced a recent bottleneck ($P<0.05$) (Table 9). Under the TPM, the Sign tests revealed that the JX, WXb, XT, DTL, DTLs, and Jap may have experienced a recent bottleneck whereas Wilcoxon's signed rank tests showed 22 populations experienced a bottleneck. Under the SMM, the Sign tests revealed that the population SH, JX, HHL, and CHL may have experienced a recent bottleneck, while Wilcoxon's signed rank tests detected that only the population JX may have experienced a recent bottleneck.

Six haplotypes of mitochondrial COI were found in the partial COI sequence of *P. clarkii*, and the length was 637bp. The haplotype diversity of the partial COI sequence (*Hd*) was 0.419, variance of haplotype diversity was 0.00188, and standard deviation of haplotype diversity was 0.043. The nucleotide composition of all haplotypes was 40.6% T, 12.7% C, 26.7% A, and 20.0% G. The nucleotide diversity was 0.267%. There were some base substitutions but no base insertions or deletions found. Twelve parsimony informative sites and three singleton variable sites were detected in the COI sequences (Table 8). Under the Kimura two-parameter model, the overall mean pairwise genetic distance of the six haplotypes was 0.011.

Six haplotypes were found in 145 individuals. The frequency of haplotype 1 was highest (107 individuals), mainly distributed among populations collected in China and Japan. The haplotypes 3, 4 and 5 were only detected in populations collected in America (Table 8). The genetic diversity parameters of the COI gene in different populations of *P. clarkii* (Table 9) demonstrated that the highest haplotype diversity was in the SH population (*Hd*= 0.571), the highest nucleotide diversity was the Ame population (*Pi*= 0.00614), and the lowest genetic diversity in the DTL, DTLs, LZL, PYL, CJr, XG, XYw and QJ populations (*Pi*= 0.0000, *Hd*= 0.000).

AMOVA revealed that 52.54% of genetic variation could be explained by variation within populations, whereas 47.46% came from variation among populations (Table 12). Genetic distance (0.005-0.006) between the American population and populations in China was high, and genetic distance varied from 0.000 to 0.006 among all populations. Genetic diversity (*Fst*) in 15 populations of *P. clarkii* ranged from a low of -0.166 between SH and DY to a high of 0.721 between Ame and five populations in China (DTL, LZL, PYL, XG, Xyw and QJ) (Table 13). Based on the genetic distances matrix, the Neighbor-joining tree was constructed among 145 individuals, and showed that the genetic distance between populations collected in America and China was highest (Figure 2).

The NJ dendrogram of six haplotypes detected in 15 populations of *P. clarkii* was constructed which showed that one branch included Hap 1, 2, 3 and 6, and the other one included Hap 4 and 5 (Figure 4).

The detection of population expansion was performed using *Fu* and *Li's* Test. The positive *Fs* values were 1.859 (P=0.124) which indicated that the red swamp crayfish populations did not experience significant population expansion. Moreover, the wave curve was obtained by population size changes analysis showed that the red swamp crayfish populations did not experience significant population expansion as well (Figure 4).

Three haplotypes were found in the 16SrRNA sequence of *P. clarkii*, which had a length of 293bp. The haplotype diversity of the 16SrRNA sequence (*Hd*) was 0.431, the variance of haplotype diversity was 0.00158, and the standard deviation of haplotype diversity was 0.040. The nucleotide composition of all the haplotypes was 36.5% T, 9.9% C, 34.4% A, and 19.2% G. The nucleotide diversity was 0.172%. Two parsimony informative sites and one base deletion were detected in the 16SrRNA sequences (Table 12). Under the Kimura two-parameter model, the overall mean pairwise genetic distance of the six haplotypes was 0.005. The frequency of haplotype 1 was highest (102 individuals), which mainly distributed among red swamp crayfish populations collected in China and Japan. Haplotype 3 was only detected in populations collected in America (Table 12). The genetic diversity parameters of 16SrRNA gene in different populations of *P. clarkii* showed the highest genetic diversity in the SH population and the lowest diversity in DTL, DTLs, LZL, PYL, CJr, XG, XYw and QJ populations (Table 15).

AMOVA revealed that 53.47% of genetic variation could be explained by variation within populations, whereas 46.53% came from variation among populations (Table 16). The genetic distance (0.004-0.006) between the population in America and populations in China was highest, while genetic distance varied from 0.000 to 0.006 among all populations. The genetic diversity (*Fst*) in 15 populations of *P. clarkii* ranged from a low of -0.131 between LZL and DTLs population to a high of 0.836 between Ame and three populations in China (DTL, XG, and QJ) (Table 15). Based on the genetic distances matrix, a Neighbor-joining tree was constructed among 142 individuals, and showed that the genetic distance of populations collected in America and China was highest (Figure 5).

The NJ dendrogram of three haplotypes detected in the 15 populations of *P. clarkii* was constructed which showed that one branch only included Hap 1, and the other one included Hap 2 and 3 (Figure 6).

The detection of population expansion was performed using *Fu* and *Li's* Test. The positive *Fs* values were 0.953 (P=0.269) which indicated that the red swamp crayfish populations did not experience significant population expansion. Moreover, the curve was obtained by population size changes analysis showed that the red swamp crayfish populations did not experience significant population expansion as well (Figure 7).

Survey of impacts of the red swamp crayfish invasion in China

The introduction of red swamp crayfish damaged native macrophytes, and often made lakes change from clear state to turbid. The eutrophication of lakes due to dominant phytoplankton, structure of the food web, and trophic state have changed profoundly. In red swamp crayfish stomachs, macrophyte fragments, aquatic adherent organisms, plankton, crops, and aquatic invertebrates (especially insect larvae) were found.

Red swamp crayfish was a medium for infection by fungus (for example: *Saprolegnia parasitica* and *Aphanomyces astaci*). Although it was a carrier for *Aphanomyces*, red swamp crayfish was not affected by it. Red swamp crayfish could carry other pathogenic microbes as well. This could make animals infected in the new aquatic ecosystem which was invaded by red swamp crayfish.

Red swamp crayfish was widely distributed in all kinds of water, especially in static water channels, shallow lakes, ponds and rice fields. Red swamp crayfish has the habit of digging tunnels. Some tunnels were located in the middle of rice fields, and some in the dykes, which could cause bank erosion or collapse. Generally, crayfish holes are more than 1 m deep in mid field, but only about 0.5 m deep in dykes. So they can be destructive to a rice paddy. Tunnels produced by crayfish may also threaten dam security for lakes, reservoirs and rivers.

Red swamp crayfish has an effect on the native biological diversity through competition and predation. Introduction of red swamp crayfish can make the quality of a wetland's habitat decline, directly or indirectly influence the animal and plant species, and lead to species diversity decline. Red swamp crayfish is an omnivorous animal, which mainly feeds on plankton, benthic organisms, algae, small fish, and shrimp.

After nearly 10 years, the market chain of red swamp crayfish has been developed, and it has become a pillar industry in many regions. In this chain, the first link is red swamp crayfish farming, the second processing, and the third tourism services developing by red swamp crayfish as a medium. A successful example is Xuyi Crayfish. At present, the Xuyi Crayfish already has been designated as "Chinese famous brand," "Chinese famous agricultural products," "Chinese famous dish," and "Chinese geographic indication products." The value of crayfish in 2009 was RMB 4.13 billion yuan. For the crayfish industry in Xuyi, Jiangsu Province, more than 20 million mu are in culture for crayfish. Annual trading volume has attained 100,000 tons, the annual businesses have exceeded RMB 1.5 billion yuan, and employees include more than 100,000 people. A similar example is the crayfish industry in Hubei province. The culture model, "Continuous Crayfish Rice," promotes the industry in Hubei province. Presently, the yield of crayfish in Hubei province ranks first in China, and the value of crayfish was 3 billion yuan.

DISCUSSION

Yue et al. (2010) analyzed six populations of *P. clarkii* only collected in China using nine polymorphic microsatellites. In this study, 35 populations of *P. clarkii* were selected from China and one population was selected from America and Japan, which were analyzed using 12 polymorphic microsatellites for the first time. Baguazhou township, Nanjing, Jiangsu province, showed the highest allelic and gene diversity among the populations investigated in China. The microsatellite data obtained by Yue et al. (2010) also showed that the population located in Nanjing displayed the highest allelic and gene diversity among the populations studied. So, Nanjing was probably the place of introduction for *P. clarkii* (Li et al., 2007; Yue et al., 2010).

The overall observed heterozygosity of the 37 populations studied here was 0.6723, the overall gene diversity was 0.7913, and the overall polymorphism information content (*PIC*) was 0.7551. All of the red swamp crayfish populations evaluated by us showed high genetic diversity. High genetic diversity of introduced populations could be caused by multiple introductions (Berg et al., 2002; Kolbe et al., 2004; Barbaresi et al., 2003; Barbaresi et al., 2007; Chu et al., 2007), or single introductions of large numbers of individuals from different populations (Stepien et al., 2002; Barbaresi et al., 2007; Chu et al., 2007; Herborg et al., 2007). Moreover, high genetic diversity of an invasive species may be caused by hybridization and variation after invading the new environment (Xu and Ye, 2003; Chen and Yan, 2005; Shi and Ma, 2006; Chu et al., 2007). Thus, the high genetic diversity of red swamp crayfish in China might derive from multiple introduction events or a single introduction of large numbers of individuals from different populations.

The genetic diversity of invasive populations would be lower than the origin population after experiencing bottleneck and founder effects if invaders were introduced only once (Amsellem et al., 2000; Dlugosch and Parker, 2008). Lower genetic diversity may be due to the invasive populations experiencing bottlenecks and genetic drift (Friar et al., 2000; Tsutsui et al., 2001). However, if the invasive species originated from multiple introductions, their population genetic diversity would not necessarily be lower than the origin place (Maron et al., 2004; Keller and Taylor, 2008). For example, the genetic diversity and heritable phenotypic variation of *Phalaris arundinacea* in the invasion locations in North America were higher than the origin in Europe. In this study, we found that Baguazhou township, Nanjing, Jiangsu province, showed the highest allelic and gene diversity among the populations investigated in China, however, the diversity was less than in America and Japan. Moreover, most of the red swamp crayfish populations may have experienced a recent bottleneck. Thus, we could speculate that red swamp crayfish populations in China derived from a single introduction of large numbers of individuals from different populations, rather than from multiple introductions. *P. clarkii* may have been introduced only once from Japan to Nanjing in 1929 (Li et al., 2007; Xia et al., 2009). However, Chinese researchers lacked the knowledge of source and dispersal, and cannot exclude the possibility of multiple introductions.

Wang et al. (2009) considered that the genetic distance of Nanjing and Nanchang populations was less than that of Nanjing and Xuyi populations due to the higher rate of gene flow among the Nanjing and Nanchang populations collected along the Changjiang River. The level of genetic differentiation among Xinanjiang and other populations was high, also indicated that exchange among the water system was the main dispersal method of red swamp crayfish. Here, the rate of gene flow among population BGt and other populations along the Changjiang River, such as WX, MAS, CJr, etc, was also higher than that of Nanjing and two Xuyi populations. All of these trends indicated that movement among the water system was the one of main dispersal means for red swamp crayfish.

Dispersal of exotic species is often influenced by human factors (Parker et al., 1999; Suarez et al., 2001), especially in fresh water ecological systems (Maria and Rebelo, 2007). Human activities can result in large and disjointed dispersal of invasive species (Suarez et al., 2001; Tiunov et al., 2006). In our study, the gene flow was high among populations which are separated by a great distance. The AMOVA of microsatellites, mitochondrial COI and 16SrRNA sequences revealed that most genetic variation (>50%) could be explained by the variation within populations. Taken together, human activities, such as movement of aquaculture crops, impelled the exchange among populations of red swamp crayfish, and had an influence on their population genetic structure.

Our results showed that red swamp crayfish may endanger native species by eating native animals and plants. They could sometimes carry and spread diseases, which may also harm native species. Meanwhile, they could destroy rice fields and water conservation projects due to their tunneling habits. Moreover, there are few natural enemies of red swamp crayfish in China (Li et al., 2005), so that red swamp crayfish could establish populations very fast and spread easily. They would endanger local fish, shellfish, and aquatic plants, as well as threaten the local food chain and damage crops and natural vegetation (Gherardi et al., 2001; Renai and Gherardi, 2004). While red swamp crayfish have been included in the list of harmful invasive species, it has also become an important freshwater resource in China. Presently, under the large demands of red swamp crayfish in the domestic and international market, cultivation of red swamp crayfish is increasing in Hubei, Jiangsu and Anhui provinces.

ANTICIPATED BENEFITS

The red swamp crayfish has become a successful worldwide invader. This study used the red swamp crayfish as a model to study changes of population structure due to anthropogenic activities during invasion and fast dispersal after invasion, to identify source area(s) or invasion center(s) as well as the dispersal patterns, to explore populations derived from single or multiple introduction events, and to evaluate the impacts of the red swamp crayfish invasion in China.

ACKNOWLEDGMENTS

We are grateful to many friends who are not listed in detail here for helping collect samples and offering some technical assistance, and the Key Laboratory of Agricultural Animal Genetics and Breeding, Ministry of Education, HZAU, China, for providing the research field and lab assistance.

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Table 1. Sampling sites for red swamp crayfish, *P. clarkii*.

No.	pop.ID	abbr. of pop.	province
1	Shanghai	SH	Shanghai municipality
2	Ningbo	NB	Zhejiang
3	Jiaxing	JX	Zhejiang
4	Xuyi-culture	XYc	Jiangsu
5	Xuyi-wild	XYw	Jiangsu
6	Wuxi binhu	WXb	Jiangsu
7	Nantong	NT	Jiangsu
8	Xiaguan District	XG	Jiangsu
9	Xiaba village	XBv	Jiangsu
10	Baguazhou township	BGt	Jiangsu
11	Wuxi	WX	Jiangsu
12	Wangjiang	WJ	Anhui
13	Maanshan	MAS	Anhui
14	Guangfengwei section of Changjiang river	CJr	Anhui
15	Chaohu lake	CHL	Anhui
16	Hefei	HF	Anhui
17	Dingyuan	DY	Anhui
18	Sanli township	SLt	Jiangxi
19	Nanbei Port	NBp	Jiangxi
20	Poyang lake	PYL	Jiangxi
21	Nanchang youlan	NCyl	Jiangxi
22	Nanhu lake	NHL	Hubei
23	Yuni lake	YNL	Hubei
24	Xiantao	XT	Hubei
25	Qianjiang	QJ	Hubei
26	Liangzi lake	LZL	Hubei
27	Honghu lake	HHL	Hubei
28	Changhu lake	CHL	Hubei
29	Yuanjiang	YJ	Hunan
30	Ningxiang	NX	Hunan
31	Dongting lake	DTL	Hunan
32	Dongting lakeside	DTLs	Hunan
33	Chongqing suburb	CQs	Chongqing municipality
34	Zhongxian	ZX	Sichuan
35	Jianyang	JY	Sichuan
36	Japan	Jap	Japan
37	America	Ame	America

Table 2. Sampling sites number of samples for mitochondrial COI and 16SrRNA analysis.

No.	pop.ID	abbr. of pop.	Number of samples for COI	Number of samples for 16SrRNA
1	Dongting lake	DTL	10	10
2	Dongting lakeside	DTLs	9	8
3	Liangzi lake	LZL	10	9
4	Poyang lake	PYL	10	8
5	Guangfengwei section of Changjiang River	CJr	8	10
6	Dingyuan	DY	10	10
7	Maanshan	MAS	10	10
8	Xiaguan District	XG	10	10
9	Shanghai	SH	8	10
10	Xuyi-wild	XYw	10	8
11	Sichuan Jianyang	JY	10	9
12	Jiaxing	JX	10	10
13	Qianjiang	QJ	10	10
14	Saitama Prefecture，Japan	Jap	10	10
15	Louisiana，America	Ame	10	10

Table 3. The mean number of alleles (*Na*), mean number of effective alleles (*Ne*), mean polymorphism information content (*PIC*), mean observed heterozygosity (*H*o) and mean expected heterozygosity (*He*)of 12 microsatellite loci in the *P. clarkii* populations.

Population ID	Na	Ne	Ho	He	PIC
SH	11.7500	6.4795	0.7887	0.8214	0.7903
NB	10.4167	5.3597	0.5880	0.8068	0.7738
JX	8.0833	5.4123	0.6632	0.7860	0.7441
XYc	9.5000	5.3707	0.7425	0.7998	0.7623
XYw	9.6667	5.4454	0.7342	0.7933	0.7542
WXb	9.2500	5.7829	0.6416	0.7978	0.7578
NT	10.0833	5.5798	0.6181	0.8211	0.7931
XG	10.0833	6.2292	0.5602	0.8151	0.7792
XBv	10.1667	5.7982	0.7836	0.7877	0.7557
BGt	11.0833	6.7329	0.6285	0.8413	0.8124
WX	10.0000	5.5924	0.7786	0.7889	0.7536
WJ	10.4167	6.1777	0.8129	0.8025	0.7672
MAS	9.5000	5.6025	0.6413	0.7771	0.7359
CJr	10.0000	5.6517	0.5777	0.7984	0.7621
CHL	10.4167	5.7354	0.7413	0.7786	0.7439
HF	8.7500	4.8770	0.6656	0.7623	0.7222
DY	8.7500	4.8386	0.6285	0.7428	0.7018
SLt	10.3333	5.7651	0.7007	0.7847	0.7497
NBp	10.6667	5.4745	0.6991	0.7969	0.7628
PYL	8.9167	4.8893	0.5890	0.7448	0.7086
NCyl	9.7500	5.8021	0.6742	0.7845	0.7433
NHL	10.7500	5.9593	0.7774	0.8194	0.7883
YNL	10.5833	5.8366	0.7361	0.8224	0.7905
XT	9.1667	5.2843	0.7096	0.7940	0.7559
QJ	9.9167	5.5028	0.6764	0.7892	0.7535
LZL	9.6667	5.6394	0.6715	0.8031	0.7658
HHL	10.6667	5.8500	0.7466	0.7924	0.7559
CHL	9.5833	4.8054	0.5875	0.7482	0.7089
YJ	7.9167	4.5335	0.5942	0.7584	0.7162
NX	8.0000	4.4062	0.5569	0.7400	0.6944
DTL	8.6667	5.0804	0.6782	0.7860	0.7459
DTLs	10.2500	5.8721	0.7038	0.8170	0.7850
CQs	9.0000	4.8829	0.7182	0.7593	0.7123
ZX	6.4167	3.6813	0.5748	0.7002	0.6553
JY	7.8333	4.3407	0.6109	0.7512	0.7113
Jap	14.3333	9.3691	0.6283	0.8873	0.8667
Ame	14.5833	8.8149	0.6465	0.8799	0.8579

Table 4. Nei's genetic identity (above diagonal) and genetic distance (below diagonal) for crayfish populations from each sampling location.

Population	SH	NB	JX	XYc	XYw	WXb	NT	XG	XBv	BGt	WX	WJ	MAS	CJr	CHL	HF	DY	SLt	NBp	PYL	NCyl	NHL	YNL	XT	QJ	LZL	HHL	CHL	YJ	NX	DTL	DTLs	CQs	ZX	JY
SH		0.557	0.604	0.720	0.662	0.621	0.605	0.582	0.651	0.566	0.700	0.693	0.572	0.507	0.650	0.731	0.500	0.717	0.712	0.578	0.599	0.617	0.544	0.696	0.678	0.667	0.704	0.610	0.576	0.582	0.588	0.577	0.704	0.630	0.678
NB	0.585		0.511	0.569	0.558	0.528	0.743	0.644	0.601	0.659	0.549	0.566	0.519	0.744	0.555	0.522	0.661	0.647	0.562	0.433	0.523	0.598	0.508	0.479	0.475	0.542	0.528	0.523	0.415	0.410	0.502	0.513	0.606	0.625	0.628
JX	0.504	0.672		0.670	0.659	0.704	0.637	0.648	0.575	0.667	0.536	0.669	0.521	0.561	0.553	0.635	0.512	0.569	0.625	0.730	0.561	0.554	0.584	0.633	0.501	0.576	0.522	0.486	0.647	0.617	0.579	0.657	0.634	0.481	0.544
XYc	0.329	0.564	0.401		**0.865**	0.747	0.666	0.608	0.818	0.655	0.704	0.814	0.671	0.571	0.678	0.810	0.681	0.703	0.822	0.756	0.622	0.757	0.790	0.820	0.588	0.808	0.747	0.690	0.682	0.780	0.732	0.774	0.746	0.725	0.801
XYw	0.412	0.583	0.417	**0.145**		0.635	0.628	0.602	0.753	0.625	0.632	0.739	0.668	0.533	0.587	0.791	0.664	0.714	0.796	0.682	0.659	0.678	0.677	0.712	0.517	0.675	0.707	0.644	0.622	0.662	0.667	0.651	0.708	0.649	0.721
WXb	0.476	0.640	0.350	0.292	0.454		0.644	0.555	0.686	0.635	0.636	0.719	0.537	0.514	0.627	0.685	0.631	0.591	0.725	0.615	0.557	0.621	0.633	0.672	0.609	0.702	0.625	0.571	0.566	0.557	0.636	0.660	0.689	0.580	0.639
NT	0.502	0.298	0.451	0.407	0.466	0.441		0.649	0.663	0.711	0.590	0.649	0.677	0.744	0.610	0.580	0.666	0.701	0.637	0.521	0.610	0.630	0.525	0.538	0.527	0.583	0.567	0.550	0.512	0.510	0.556	0.588	0.684	0.680	0.687
XG	0.542	0.440	0.433	0.497	0.507	0.588	0.433		0.553	0.779	0.518	0.645	0.499	0.753	0.560	0.501	0.506	0.606	0.535	0.654	0.469	0.547	0.586	0.587	0.475	0.579	0.449	0.414	0.671	0.635	0.598	0.629	0.599	0.502	0.496
XBv	0.429	0.509	0.554	0.201	0.284	0.377	0.412	0.592		0.628	0.743	0.843	0.751	0.514	0.572	0.779	0.726	0.747	0.841	0.634	0.678	0.768	0.696	0.678	0.538	0.788	0.710	0.689	0.529	0.595	0.668	0.674	0.783	0.770	0.809
BGt	0.569	0.417	0.405	0.423	0.470	0.455	0.341	0.249	0.465		0.515	0.634	0.566	0.709	0.533	0.541	0.591	0.596	0.621	0.614	0.542	0.578	0.555	0.539	0.450	0.561	0.507	0.470	0.552	0.553	0.560	0.618	0.545	0.518	0.548
WX	0.357	0.601	0.624	0.351	0.459	0.453	0.527	0.658	0.297	0.664		0.691	0.656	0.449	0.575	0.725	0.609	0.737	0.764	0.542	0.627	0.735	0.625	0.675	0.593	0.797	0.714	0.733	0.582	0.594	0.562	0.660	0.721	0.731	0.710
WJ	0.367	0.570	0.402	0.206	0.303	0.330	0.433	0.439	0.171	0.455	0.369		0.677	0.568	0.657	0.741	0.682	0.698	0.781	0.720	0.617	0.699	0.699	0.718	0.578	0.741	0.611	0.571	0.577	0.690	0.752	0.723	0.860	0.715	0.717
MAS	0.559	0.657	0.652	0.399	0.403	0.623	0.390	0.695	0.287	0.569	0.422	0.391		0.470	0.491	0.626	0.632	0.695	0.728	0.591	0.642	0.698	0.602	0.612	0.467	0.635	0.659	0.606	0.543	0.588	0.502	0.548	0.693	0.653	0.712
CJr	0.680	0.296	0.579	0.561	0.630	0.666	0.296	0.284	0.666	0.344	0.801	0.566	0.754		0.603	0.473	0.538	0.604	0.529	0.478	0.496	0.523	0.486	0.454	0.425	0.479	0.396	0.419	0.503	0.463	0.569	0.553	0.555	0.517	0.529
CHL	0.431	0.589	0.593	0.388	0.533	0.468	0.494	0.581	0.559	0.629	0.554	0.421	0.711	0.506		0.697	0.463	0.664	0.623	0.537	0.493	0.583	0.602	0.642	0.720	0.642	0.568	0.512	0.510	0.590	0.562	0.599	0.634	0.556	0.516
HF	0.313	0.651	0.455	0.211	0.235	0.378	0.545	0.691	0.250	0.614	0.321	0.300	0.469	0.749	0.361		0.655	0.722	0.810	0.570	0.689	0.705	0.695	0.744	0.585	0.746	0.745	0.657	0.570	0.597	0.598	0.641	0.723	0.692	0.737
DY	0.694	0.415	0.670	0.385	0.409	0.460	0.407	0.681	0.321	0.526	0.497	0.383	0.459	0.619	0.770	0.423		0.645	0.661	0.426	0.582	0.649	0.584	0.479	0.431	0.620	0.631	0.567	0.429	0.449	0.539	0.582	0.687	0.701	0.721
SLt	0.333	0.435	0.565	0.352	0.337	0.527	0.355	0.500	0.292	0.517	0.306	0.360	0.364	0.504	0.410	0.326	0.439		0.759	0.565	0.671	0.714	0.620	0.620	0.584	0.710	0.704	0.691	0.518	0.533	0.562	0.578	0.747	0.746	0.756
NBp	0.340	0.577	0.471	0.196	0.229	0.322	0.452	0.625	0.173	0.476	0.269	0.248	0.318	0.637	0.474	0.211	0.414	0.275		0.617	0.701	0.731	0.707	0.696	0.605	0.748	0.726	0.729	0.575	0.600	0.655	0.639	0.777	0.726	0.800
PYL	0.548	0.838	0.315	0.280	0.383	0.486	0.651	0.425	0.455	0.488	0.612	0.329	0.525	0.738	0.621	0.562	0.853	0.571	0.483		0.532	0.684	0.691	0.759	0.533	0.704	0.584	0.521	0.706	0.800	0.683	0.730	0.613	0.532	0.567
NCyl	0.513	0.647	0.578	0.474	0.416	0.585	0.494	0.757	0.388	0.612	0.467	0.482	0.443	0.701	0.707	0.373	0.541	0.400	0.355	0.630		0.621	0.579	0.569	0.483	0.587	0.567	0.681	0.430	0.479	0.520	0.583	0.617	0.554	0.643
NHL	0.482	0.515	0.590	0.279	0.388	0.477	0.462	0.603	0.264	0.548	0.309	0.358	0.360	0.649	0.540	0.349	0.433	0.337	0.313	0.380	0.477		0.745	0.782	0.600	0.825	0.740	0.726	0.644	0.739	0.670	0.716	0.659	0.742	0.755
YNL	0.610	0.677	0.537	0.236	0.390	0.458	0.645	0.535	0.363	0.589	0.471	0.358	0.507	0.722	0.508	0.364	0.539	0.479	0.348	0.370	0.547	0.294		0.815	0.570	0.747	0.609	0.587	0.693	0.777	0.694	0.789	0.624	0.620	0.725
XT	0.363	0.736	0.458	0.199	0.339	0.398	0.620	0.533	0.388	0.619	0.393	0.331	0.492	0.790	0.443	0.296	0.736	0.479	0.363	0.276	0.565	0.246	0.204		0.635	0.803	0.698	0.671	0.739	0.829	0.675	0.768	0.673	0.584	0.685
QJ	0.389	0.745	0.691	0.532	0.660	0.496	0.640	0.745	0.620	0.800	0.523	0.548	0.762	0.857	0.328	0.536	0.842	0.537	0.502	0.629	0.729	0.511	0.562	0.455		0.676	0.601	0.555	0.532	0.543	0.596	0.572	0.614	0.478	0.479
LZL	0.406	0.613	0.553	0.213	0.393	0.354	0.541	0.547	0.238	0.578	0.227	0.299	0.455	0.737	0.443	0.293	0.479	0.343	0.290	0.351	0.533	0.193	0.291	0.219	0.392		0.765	0.721	0.635	0.723	0.689	0.769	0.673	0.707	0.708
HHL	0.352	0.640	0.651	0.291	0.347	0.471	0.568	0.802	0.343	0.680	0.337	0.492	0.417	0.926	0.566	0.295	0.460	0.350	0.321	0.538	0.568	0.301	0.496	0.360	0.510	0.268		0.745	0.588	0.653	0.545	0.602	0.632	0.654	0.764
CHL	0.495	0.648	0.722	0.372	0.440	0.561	0.598	0.881	0.372	0.755	0.311	0.561	0.501	0.870	0.670	0.420	0.568	0.369	0.316	0.652	0.384	0.320	0.532	0.399	0.589	0.328	0.294		0.525	0.540	0.568	0.603	0.632	0.635	0.672
YJ	0.551	0.879	0.435	0.383	0.475	0.569	0.670	0.400	0.637	0.595	0.542	0.550	0.611	0.687	0.674	0.563	0.846	0.657	0.553	0.348	0.843	0.440	0.367	0.302	0.631	0.454	0.532	0.644		0.769	0.619	0.658	0.564	0.501	0.560
NX	0.541	0.892	0.483	0.249	0.413	0.586	0.673	0.455	0.519	0.593	0.522	0.371	0.531	0.770	0.527	0.516	0.801	0.629	0.511	0.223	0.736	0.302	0.253	0.188	0.611	0.324	0.426	0.616	0.263		0.692	0.771	0.606	0.547	0.622
DTL	0.531	0.689	0.546	0.312	0.406	0.452	0.588	0.515	0.403	0.581	0.577	0.285	0.690	0.564	0.577	0.515	0.618	0.576	0.423	0.381	0.654	0.401	0.366	0.394	0.517	0.373	0.607	0.566	0.480	0.368		0.737	0.651	0.648	0.607
DTLs	0.550	0.667	0.420	0.256	0.430	0.415	0.532	0.464	0.394	0.482	0.416	0.325	0.601	0.592	0.513	0.446	0.542	0.549	0.448	0.315	0.540	0.334	0.237	0.264	0.559	0.262	0.507	0.506	0.419	0.261	0.305		0.619	0.590	0.659
CQs	0.352	0.501	0.456	0.293	0.345	0.373	0.380	0.512	0.245	0.606	0.327	0.151	0.367	0.588	0.455	0.324	0.375	0.292	0.252	0.489	0.482	0.417	0.472	0.396	0.487	0.396	0.459	0.458	0.572	0.501	0.430	0.480		0.736	0.712
ZX	0.463	0.470	0.733	0.322	0.432	0.544	0.385	0.690	0.261	0.658	0.313	0.336	0.426	0.660	0.586	0.368	0.355	0.294	0.321	0.631	0.591	0.298	0.478	0.538	0.738	0.347	0.425	0.455	0.692	0.603	0.434	0.527	0.306		0.836
JY	0.389	0.465	0.609	0.221	0.327	0.448	0.375	0.700	0.212	0.602	0.343	0.332	0.340	0.636	0.662	0.305	0.327	0.280	0.224	0.568	0.442	0.281	0.321	0.379	0.736	0.345	0.269	0.397	0.579	0.474	0.500	0.418	0.340	0.179	
Jap	0.923	0.664	0.720	0.824	0.837	0.849	0.652	0.639	0.836	0.399	0.965	0.733	0.840	0.719	0.881	0.953	0.833	0.919	0.872	0.796	0.914	0.803	0.817	0.946	0.958	0.989	0.924	0.955	0.836	0.965	0.833	0.791	0.943	**0.999**	0.937
Ame	0.697	0.630	0.835	0.856	0.684	0.873	0.618	0.609	0.878	0.493	0.860	0.777	0.891	0.709	0.935	0.925	0.955	0.833	0.868	**0.996**	0.919	0.743	0.880	0.851	0.886	0.970	0.893	0.905	0.851	0.948	0.784	0.845	0.919	0.956	0.928

Table 5. Gene flow (above diagonal) and genetic diversity (*Fst*) (below diagonal) in 37 *P. clarkii* populations.

Population	SH	NB	JX	XYc	XYw	WXb	NT	XG	XBv	BGt	WX	WJ	MAS	CJr	CHL	HF	DY	SLt	NBp	PYL	NCyl	NHL	YNL	XT	QJ	LZL	HHL	CHL	YJ	NX	DTL	DTLs	CQs	ZX	JY
SH		2.607	2.806	4.370	3.574	3.054	3.188	2.852	3.211	3.044	3.831	3.976	2.443	2.239	3.174	3.902	1.831	3.988	4.128	2.206	2.817	3.252	2.692	3.868	3.504	3.616	3.911	2.479	2.302	2.237	2.672	2.868	3.440	2.238	3.071
NB	0.088		2.111	2.519	2.448	2.273	4.982	3.238	2.639	3.756	2.311	2.530	2.060	4.504	2.271	1.986	2.679	2.966	2.430	1.552	2.212	2.903	2.347	2.005	1.939	2.388	2.202	1.926	1.570	1.491	2.080	2.322	2.419	2.117	2.521
JX	0.082	0.106		3.205	3.104	3.558	3.075	3.138	2.309	3.627	2.114	3.224	1.952	2.307	2.185	2.531	1.717	2.247	2.721	3.370	2.248	2.441	2.678	2.838	1.938	2.456	2.039	1.656	2.620	2.295	2.341	3.256	2.491	1.450	1.923
XYc	0.054	0.090	0.072		10.595	4.431	3.552	2.875	6.440	3.616	3.617	6.498	3.030	2.434	3.280	5.540	2.796	3.521	6.841	3.768	2.756	5.083	6.116	6.708	2.467	6.422	4.393	2.980	2.933	4.189	3.998	5.544	3.806	2.900	5.012
XYw	0.065	0.093	0.075	0.023		2.946	3.110	2.811	4.436	3.271	2.859	4.392	3.030	2.227	2.474	5.077	2.665	3.746	5.945	2.856	3.070	3.662	3.692	3.914	2.093	3.445	3.745	2.603	2.502	2.655	3.206	3.301	3.376	2.246	3.414
WXb	0.076	0.099	0.066	0.053	0.078		3.266	2.457	3.375	3.350	2.850	3.988	2.073	2.115	2.723	3.085	2.390	2.446	4.019	2.267	2.276	3.026	3.179	3.267	2.605	3.797	2.766	2.055	2.087	1.940	2.822	3.409	3.034	1.848	2.537
NT	0.073	0.048	0.075	0.066	0.074	0.071		3.500	3.344	5.060	2.713	3.366	3.359	4.778	2.728	2.399	2.829	3.782	3.179	1.943	2.856	3.436	2.601	2.432	2.300	2.800	2.544	2.130	2.001	1.898	2.484	2.991	3.229	2.553	3.166
XG	0.081	0.072	0.074	0.080	0.082	0.092	0.067		2.382	6.806	2.204	3.244	2.022	4.776	2.316	1.930	1.805	2.673	2.344	2.700	1.973	2.651	2.974	2.683	1.970	2.694	1.882	1.529	2.981	2.539	2.692	3.279	2.414	1.587	1.841
XBv	0.072	0.087	0.098	0.037	0.053	0.069	0.070	0.095		3.132	4.124	7.846	4.039	2.051	2.299	4.461	3.228	4.088	7.561	2.356	3.169	5.066	3.750	3.219	2.110	5.471	3.584	2.919	1.871	2.102	3.111	3.397	4.534	3.471	5.083
BGt	0.076	0.062	0.064	0.065	0.071	0.069	0.047	0.035	0.074		2.369	3.405	2.542	4.319	2.437	2.265	2.357	2.810	3.171	2.527	2.528	3.104	2.951	2.557	2.050	2.806	2.338	1.867	2.267	2.175	2.634	3.418	2.251	1.758	2.221
WX	0.061	0.098	0.106	0.065	0.080	0.081	0.084	0.102	0.057	0.095		3.499	2.828	1.801	2.327	3.500	2.198	3.946	4.654	1.852	2.743	4.372	2.968	3.194	2.432	5.816	3.696	3.536	2.137	2.112	2.240	3.243	3.399	2.949	3.158
WJ	0.059	0.090	0.072	0.037	0.054	0.059	0.069	0.072	0.031	0.068	0.067		3.137	2.444	3.053	3.847	2.820	3.505	5.324	3.255	2.690	3.991	4.005	3.938	2.431	4.481	2.684	2.084	2.184	2.891	4.427	4.332	8.109	2.805	3.342
MAS	0.093	0.108	0.114	0.076	0.076	0.108	0.069	0.110	0.058	0.090	0.081	0.074		1.801	1.827	2.389	2.267	3.176	3.752	2.038	2.667	3.564	2.654	2.497	1.741	2.751	2.860	2.169	1.871	2.004	1.873	2.269	2.920	2.154	3.048
CJr	0.100	0.053	0.098	0.093	0.101	0.106	0.050	0.050	0.109	0.055	0.122	0.093	0.122		2.516	1.737	1.871	2.529	2.172	1.649	1.993	2.313	2.156	1.851	1.710	2.000	1.632	1.495	1.812	1.605	2.354	2.458	2.046	1.592	1.902
CHL	0.073	0.099	0.103	0.071	0.092	0.084	0.084	0.097	0.098	0.093	0.097	0.076	0.120	0.090		3.179	1.548	2.937	2.715	1.832	1.889	2.613	2.776	2.876	3.720	2.961	2.247	1.736	1.793	2.079	2.211	2.729	2.496	1.707	1.790
HF	0.060	0.112	0.090	0.043	0.047	0.075	0.094	0.115	0.053	0.099	0.067	0.061	0.095	0.126	0.073		2.364	3.367	5.489	1.849	2.998	3.506	3.401	3.844	2.195	3.990	3.804	2.434	1.924	1.990	2.261	2.783	3.147	2.401	3.300
DY	0.120	0.085	0.127	0.082	0.086	0.095	0.081	0.122	0.072	0.096	0.102	0.081	0.099	0.118	0.139	0.096		2.396	2.601	1.284	2.015	2.649	2.228	1.629	1.462	2.346	2.335	1.780	1.344	1.342	1.833	2.184	2.594	2.342	2.868
SLt	0.059	0.078	0.100	0.066	0.063	0.093	0.062	0.086	0.058	0.082	0.060	0.067	0.073	0.090	0.078	0.069	0.094		4.451	1.924	3.095	3.903	2.856	2.625	2.333	3.695	3.440	2.921	1.798	1.786	2.204	2.497	3.721	3.067	3.745
NBp	0.057	0.093	0.084	0.035	0.040	0.059	0.073	0.096	0.032	0.073	0.051	0.045	0.062	0.103	0.084	0.044	0.088	0.053		2.281	3.596	4.402	4.011	3.497	2.564	4.547	3.941	3.506	2.132	2.181	2.996	3.102	4.420	2.893	4.902
PYL	0.102	0.139	0.069	0.062	0.080	0.099	0.114	0.085	0.096	0.090	0.119	0.071	0.109	0.132	0.120	0.119	0.163	0.115	0.099		1.819	2.981	3.084	3.828	1.807	3.064	2.043	1.556	2.745	4.146	2.738	3.493	2.058	1.455	1.782
NCyl	0.082	0.102	0.100	0.083	0.075	0.099	0.080	0.112	0.073	0.090	0.084	0.085	0.086	0.111	0.117	0.077	0.110	0.075	0.065	0.121		2.936	2.618	2.361	1.884	2.516	2.274	2.903	1.543	1.601	2.050	2.601	2.398	1.691	2.490
NHL	0.071	0.079	0.093	0.047	0.064	0.076	0.068	0.086	0.047	0.075	0.054	0.059	0.066	0.098	0.087	0.067	0.086	0.060	0.054	0.077	0.078		5.240	5.672	2.728	7.729	4.531	3.629	2.764	3.685	3.481	4.475	2.928	3.251	4.090
YNL	0.085	0.096	0.085	0.039	0.063	0.073	0.088	0.078	0.063	0.078	0.078	0.059	0.086	0.104	0.083	0.068	0.101	0.080	0.059	0.075	0.087	0.046		6.968	2.544	4.935	2.851	2.324	3.274	4.407	3.772	6.549	2.652	2.191	3.634
XT	0.061	0.111	0.081	0.036	0.060	0.071	0.093	0.085	0.072	0.089	0.073	0.060	0.091	0.119	0.080	0.061	0.133	0.087	0.067	0.061	0.096	0.042	0.035		2.771	6.067	3.471	2.724	3.621	5.642	3.208	5.233	2.875	1.864	2.904
QJ	0.067	0.114	0.114	0.092	0.107	0.088	0.098	0.113	0.106	0.109	0.093	0.093	0.126	0.128	0.063	0.102	0.146	0.097	0.089	0.122	0.117	0.084	0.089	0.083		3.295	2.502	1.929	1.877	1.842	2.453	2.510	2.349	1.446	1.665
LZL	0.065	0.095	0.092	0.037	0.068	0.062	0.082	0.085	0.044	0.082	0.041	0.053	0.083	0.111	0.078	0.059	0.096	0.063	0.052	0.075	0.090	0.031	0.048	0.040	0.071		4.852	3.372	2.586	3.298	3.474	5.430	2.976	2.769	3.240
HHL	0.060	0.102	0.109	0.054	0.063	0.083	0.089	0.117	0.065	0.097	0.063	0.085	0.080	0.133	0.100	0.062	0.097	0.068	0.060	0.109	0.099	0.052	0.081	0.067	0.091	0.049		3.693	2.187	2.483	2.160	2.736	2.510	2.232	3.958
CHL	0.092	0.115	0.131	0.077	0.088	0.108	0.105	0.141	0.079	0.118	0.066	0.107	0.103	0.143	0.126	0.093	0.123	0.079	0.067	0.138	0.079	0.064	0.097	0.084	0.115	0.069	0.063		1.649	1.625	1.982	2.362	2.241	1.910	2.468
YJ	0.098	0.137	0.087	0.079	0.091	0.107	0.111	0.077	0.118	0.099	0.105	0.103	0.118	0.121	0.122	0.115	0.157	0.122	0.105	0.083	0.139	0.083	0.071	0.065	0.118	0.088	0.103	0.132		3.639	2.332	2.861	1.871	1.396	1.828
NX	0.101	0.144	0.098	0.056	0.086	0.114	0.116	0.090	0.106	0.103	0.106	0.080	0.111	0.135	0.107	0.112	0.157	0.123	0.103	0.057	0.135	0.064	0.054	0.042	0.120	0.070	0.091	0.133	0.064		2.835	4.258	2.017	1.496	2.053
DTL	0.086	0.107	0.097	0.059	0.072	0.081	0.091	0.085	0.074	0.087	0.100	0.053	0.118	0.096	0.102	0.100	0.120	0.102	0.077	0.084	0.109	0.067	0.062	0.072	0.093	0.067	0.104	0.112	0.097	0.081		4.451	2.583	2.165	2.253
DTLs	0.080	0.097	0.071	0.043	0.070	0.068	0.077	0.071	0.069	0.068	0.072	0.055	0.099	0.092	0.084	0.082	0.103	0.091	0.075	0.067	0.088	0.053	0.037	0.046	0.091	0.044	0.084	0.096	0.080	0.055	0.053		2.562	1.999	2.826
CQs	0.068	0.094	0.091	0.062	0.069	0.076	0.072	0.094	0.052	0.100	0.069	0.030	0.079	0.109	0.091	0.074	0.088	0.063	0.054	0.108	0.094	0.079	0.086	0.080	0.096	0.078	0.091	0.100	0.118	0.110	0.088	0.089		2.774	2.923
ZX	0.100	0.106	0.147	0.079	0.100	0.119	0.089	0.136	0.067	0.124	0.078	0.082	0.104	0.136	0.128	0.094	0.096	0.075	0.080	0.147	0.129	0.071	0.102	0.118	0.147	0.083	0.101	0.116	0.152	0.143	0.104	0.111	0.083		4.715
JY	0.075	0.090	0.115	0.048	0.068	0.090	0.073	0.120	0.047	0.101	0.073	0.070	0.076	0.116	0.123	0.070	0.080	0.063	0.049	0.123	0.091	0.058	0.064	0.079	0.131	0.072	0.059	0.092	0.120	0.109	0.100	0.081	0.079	0.050	
Jap	0.091	0.079	0.089	0.093	0.094	0.094	0.071	0.073	0.098	0.044	0.106	0.085	0.103	0.086	0.102	0.116	0.116	0.106	0.098	0.112	0.101	0.085	0.084	0.103	0.106	0.102	0.103	0.121	0.110	0.125	0.098	0.085	0.117	0.142	0.119
Ame	0.078	0.077	0.099	0.097	0.085	0.098	0.070	0.071	0.103	0.054	0.102	0.090	0.109	0.087	0.108	0.116	0.127	0.102	0.100	0.128	0.103	0.082	0.091	0.099	0.104	0.103	0.103	0.118	0.113	0.125	0.096	0.090	0.117	0.141	0.120

Table 6. Analysis of molecular variance (AMOVA) within and among *P. clarkii* populations.

Source of variance	degree of freedom	Sum of squares	Variance components	Percentage of variation(%)
Among populations	36	1702.299	0.44426	8.74
Within populations	3515	16300.219	4.63733	91.26
Total	3551	18002.517	5.08159	

Table 7. Sign tests and Wilcoxon tests for heterozygosity excess at twelve microsatellite loci in six *P. clarkii* populations.

Pop	IAM			TPM			SMM		
	HeE	He/Hd	Ps/Pw	HeE	He/Hd	Ps/Pw	HeE	He/Hd	Ps/Pw
SH	7.21	12/0	**0.002/0.000**	7.1	8/4	0.415/**0.039**	7.16	2/10	**0.003**/0.983
NB	7.23	9/3	0.230/**0.032**	7.21	8/4	0.440/0.545	7.06	6/6	0.366/0.788
JX	6.98	12/0	**0.002/0.000**	7.07	12/0	**0.002/0.000**	7.08	11/1	**0.017/0.017**
XYc	7.20	11/1	**0.020/0.000**	7.1	10/2	0.075/**0.021**	7.05	5/7	0.181/0.285
XYw	7.24	11/1	**0.021/0.000**	7.12	8/4	0.419/**0.046**	7.07	4/8	0.067/0.924
WXb	6.96	12/0	**0.001/0.000**	6.91	11/1	**0.013/0.000**	6.88	7/5	0.592/0.424
NT	7.22	11/1	**0.020/0.000**	7.16	10/2	0.080/0.065	7.02	4/8	0.071/0.954
XG	7.18	12/0	**0.002/0.000**	7.13	10/2	0.077/**0.001**	7.12	5/7	0.171/0.689
XBv	7.25	11/1	**0.021/0.000**	7.13	9/3	0.213/0.117	7.01	4/8	0.072/0.954
BGt	7.31	12/0	**0.003/0.000**	7.14	10/2	0.078/**0.001**	7.09	6/6	0.360/0.515
WX	7.13	11/1	**0.018/0.017**	7.07	9/3	0.203/**0.046**	7.09	6/6	0.360/0.380
WJ	7.16	12/0	**0.002/0.000**	7.17	10/2	0.081/**0.007**	7.14	6/6	0.347/0.765
MAS	7.12	12/0	**0.002/0.000**	7.11	9/3	0.210/**0.004**	7.12	5/7	0.170/0.849
CJr	7.17	10/2	0.080/**0.000**	7.17	9/3	0.221/0.102	7.08	6/6	0.362/0.830
CHL	7.11	11/1	**0.017/0.000**	7.12	9/3	0.211/0.088	7.09	3/9	**0.018**/0.961
HF	7.17	10/2	0.080/**0.000**	7.04	7/5	0.600/0.235	7.02	6/6	0.376/0.380
DY	7.08	11/1	**0.016/0.000**	7.15	8/4	0.426/0.170	7.11	5/7	0.172/0.898
SLt	7.10	12/0	**0.002/0.000**	7.09	9/3	0.206/**0.021**	7.11	2/10	**0.003**/0.993
NBp	7.21	11/1	**0.020/0.000**	7.10	9/3	0.208/0.259	7.07	3/9	**0.018**/0.998
PYL	6.97	10/2	0.065/**0.002**	7.03	8/4	0.398/0.190	7.12	6/6	0.351/0.867
NCyl	7.17	12/0	**0.002/0.000**	7.14	7/5	0.576/0.055	7.08	6/6	0.362/0.898
NHL	7.21	12/0	**0.002/0.000**	7.10	8/4	0.415/**0.046**	7.06	6/6	0.365/0.715
YNL	7.24	11/1	**0.021/0.000**	7.14	8/4	0.424/0.076	7.08	6/6	0.362/0.830
XT	7.10	12/0	**0.002/0.000**	7.13	11/1	**0.0178/0.002**	7.10	4/8	0.064/0.830
QJ	7.18	11/1	**0.019/0.000**	7.06	8/4	0.405/0.170	7.00	6/6	0.379/0.810
LZL	7.19	12/0	**0.002/0.000**	7.13	9/3	0.213/**0.004**	7.12	5/7	0.169/0.912
HHL	7.16	11/1	**0.019/0.000**	7.13	10/2	0.078/**0.032**	7.07	2/10	**0.004**/0.993

Pop	IAM			TPM			SMM		
	HeE	He/Hd	Ps/Pw	HeE	He/Hd	Ps/Pw	HeE	He/Hd	Ps/Pw
CHL	7.18	10/2	0.081/**0.026**	7.05	7/5	0.597/0.455	7.13	1/11	**0.000**/0.999
YJ	7.15	12/0	**0.002/0.000**	7.15	8/4	0.427/**0.021**	7.10	5/7	0.173/0.898
NX	7.08	12/0	**0.002/0.000**	7.08	6/6	0.362/0.088	7.14	6/6	0.348/0.924
DTL	7.15	12/0	**0.002/0.000**	7.14	11/1	**0.018/0.000**	7.09	4/8	0.065/0.849
DTLs	7.24	11/1	**0.021/0.000**	7.07	11/1	**0.016/0.017**	7.06	4/8	0.067/0.924
CQs	7.08	12/0	**0.001/0.000**	7.18	9/3	0.222/**0.046**	7.11	4/8	0.064/0.961
ZX	6.89	11/1	**0.012/0.000**	6.99	9/3	0.189/**0.002**	6.98	5/7	0.192/0.830
JY	7.12	11/1	**0.018/0.005**	7.15	10/2	0.079/**0.026**	7.04	5/7	0.183/0.830
Jap	7.28	12/0	**0.003/0.000**	7.20	11/1	**0.020/0.000**	7.04	9/3	0.197/0.259
Ame	7.24	12/0	**0.002/0.000**	7.10	9/3	0.208/**0.005**	7.09	5/7	0.175/0.677

Table 8. Distribution of haplotypes in COI sequences of *P. clarkia*.

	42	45	234	288	297	342	408	444	465	486	528	534	565	594	603	DTL	DTLs	LZL	PYL	CJr	DY	MAS	XG	SH	XYw	JY	JX	QJ	Jap	Ame	Tatal
Hap_1	G	A	A	T	G	A	A	A	G	G	G	A	C	G	T	10	9	10	10	8	5	2	10	4	10	7	8	10	4		107
Hap_2	.	.	.	.	A	.	.	.	A	.	.	.	.	A	.						5	8		4		3	2		6		28
Hap_3	.	.	.	C	A	.	G	.	A	.	A	.	.	A	.															7	7
Hap_4	A	.	G	A	A	G	.	G	A	A	.	G	.	A	C															1	1
Hap_5	A	G	G	A	A	G	.	G	A	.	.	G	.	A	C															1	1
Hap_6	.	.	.	C	A	.	.	.	A	.	A	.	T	A	.															1	1
Total																10	9	10	10	8	10	10	10	8	10	10	10	10	10	10	145

Table 9. Genetic diversity parameters of COI gene in different populations of *P. clarkia*.

Population	Number of samples(N)	Number of segregating sites(S)	Number of haplotypes(H)	Haplotype diversity(Hd)	Average number of differences(K)	Nucleotide diversity(Pi)
DTL	10	0	1	0.000	0.000	0.00000
DTLs	9	0	1	0.000	0.000	0.00000
LZL	10	0	1	0.000	0.000	0.00000
PYL	10	0	1	0.000	0.000	0.00000
CJr	8	0	1	0.000	0.000	0.00000
DY	10	3	2	0.556	1.667	0.00262
MAS	10	3	2	0.356	1.067	0.00168
XG	10	0	1	0.000	0.000	0.00000
SH	8	3	2	0.571	1.714	0.00270
XYw	10	0	1	0.000	0.000	0.00000
JY	10	3	2	0.467	1.400	0.00220
JX	10	3	2	0.356	1.067	0.00167
QJ	10	0	1	0.000	0.000	0.00000
Jap	10	3	2	0.533	1.600	0.00251
Ame	10	12	4	0.533	3.911	0.00614
Total	145	15	6	0.419	1.702	0.00267

Table 10. Analysis of molecular variance (AMOVA) within and among *P. clarkii* population by mtDNA COI analysis.

Source of variance	degree of freedom	Sum of squares	Variance components	Percentage of variation(%)
Among populations	14	69.83	0.46321Va	47.46
Within populations	130	66.653	0.51271Vb	52.54
Total	144	136.483	0.97583	

Table 11. Genetic distances (below diagonal)and genetic fixations index(above diagonal) of COI gene among *P. clarkii* populations.

	DTL	DTLs	LZL	PYL	CJr	DY	MAS	XG	SH	XYw	JY	JX	QJ	Jap	Ame
DTL		0.012	0.000	0.000	0.000	0.444	0.718	0.000	0.438	0.000	0.222	0.111	0.000	0.556	**0.721**
DTLs	0.000		0.012	0.012	-0.014	0.248	0.493	0.012	0.224	0.012	0.098	0.042	0.012	0.335	0.610
LZL	0.000	0.000		0.000	0.000	0.444	0.718	0.000	0.438	0.000	0.222	0.111	0.000	0.556	**0.721**
PYL	0.000	0.000	0.000		0.000	0.444	0.718	0.000	0.438	0.000	0.222	0.111	0.000	0.556	**0.721**
CJr	0.000	0.000	0.000	0.000		0.407	0.691	0.000	0.396	0.000	0.187	0.080	0.000	0.521	0.694
DY	0.001	0.001	0.001	0.001	0.001		0.078	0.444	**-0.116**	0.444	-0.022	0.089	0.444	-0.089	0.493
MAS	0.002	0.002	0.002	0.002	0.002	0.001		0.718	0.065	0.718	0.304	0.435	0.718	-0.009	0.440
XG	0.000	0.000	0.000	0.000	0.000	0.001	0.002		0.438	0.000	0.222	0.111	0.000	0.556	**0.721**
SH	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		0.438	-0.031	0.077	0.438	-0.095	0.465
XYw	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.001		0.222	0.111	0.000	0.556	**0.721**
JY	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001		-0.082	0.222	0.074	0.565
JX	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001		0.111	0.206	0.611
QJ	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.001	0.000	0.001	0.001		0.556	**0.721**
Jap	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.002		0.470
Ame	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.006	0.005	0.006	0.005	0.006	0.006	0.005	

Table 12. Distribution of haplotypes in 16SrRNA sequences of *P. clarkia*.

	95	224	293	DTL	DTLs	LZL	PYL	CJr	DY	MAS	XG	SH	XYw	JY	JX	QJ	Jap	Ame	Total
Hap_1	A	A	T	10	8	9	8	10	4	2	10	5	8	6	8	10	4		102
Hap_2	G	.	-						6	8		5		3	2		6	2	33
Hap_3	G	G	-															7	7
		Total		10	8	9	8	10	10	10	10	10	8	9	10	10	10	9	142

Table 13. Genetic diversity parameters of 16SrRNA gene in different populations of *P. clarkii*.

Population	Number of samples(N)	Number of segregating sites(S)	Number of haplotypes(H)	Haplotype diversity(Hd)	Average number of differences(K)	Nucleotide diversity(Pi)
DTL	10	0	1	0.000	0.000	0.00000
DTLs	8	0	1	0.000	0.000	0.00000
LZL	9	0	1	0.000	0.000	0.00000
PYL	8	0	1	0.000	0.000	0.00000
CJr	10	0	1	0.000	0.000	0.00000
DY	10	1	2	0.533	0.533	0.00183
MAS	10	1	2	0.356	0.356	0.00122
XG	10	0	1	0.000	0.000	0.00000
SH	10	1	2	0.556	0.556	0.00190
XYw	8	0	1	0.000	0.000	0.00000
JY	9	1	2	0.500	0.500	0.00171
JX	10	1	2	0.356	0.356	0.00122
QJ	10	0	1	0.000	0.000	0.00000
Jap	10	1	2	0.533	0.533	0.00183
Ame	10	1	2	0.467	0.467	0.00160
Total	142	2	3	0.431	0.502	0.00172

Table 14. Analysis of moleeular variance (AMOVA) within and among *Procambarus clarkii* population by mtDNA 16SrRNA analysis.

Source of variance	degree of freedom	Sum of squares	Variance components	Percentage of variation(%)
Among populations	14	31.888	0.21465 Va	46.53
Within populations	127	31.331	0.24670 Vb	53.47
Total	141	63.218	0.46135	

Table 15. Genetic distances (below diagonal) and genetic fixations index (above diagonal) of 16SrRNA sequences among *P. clarkii* populations.

	DTL	DTLs	LZL	PYL	CJr	DY	MAS	XG	SH	XYw	JY	JX	QJ	Jap	Ame
DTL		0.181	0.141	0.000	0.000	0.556	0.778	0.000	0.444	0.029	0.268	0.074	0.000	0.476	**0.836**
DTLs	0.000		**-0.131**	0.143	-0.039	0.333	0.599	0.181	0.214	-0.086	0.041	0.012	0.181	0.344	0.726
LZL	0.000	0.000		0.107	-0.057	0.362	0.621	0.141	0.242	-0.098	0.063	0.010	0.141	0.355	0.740
PYL	0.000	0.000	0.000		-0.024	0.521	0.755	0.000	0.407	0.000	0.230	0.045	0.000	0.440	0.818
CJr	0.000	0.000	0.000	0.000		0.463	0.704	0.000	0.344	-0.123	0.154	0.006	0.000	0.402	0.791
DY	0.002	0.002	0.002	0.002	0.002		-0.010	0.556	-0.089	0.416	0.031	0.289	0.556	0.151	0.387
MAS	0.003	0.003	0.003	0.003	0.003	0.002		0.778	0.089	0.671	0.290	0.554	0.778	0.388	0.372
XG	0.000	0.000	0.000	0.000	0.000	0.002	0.003		0.444	0.029	0.268	0.074	0.000	0.476	**0.836**
SH	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002		0.295	-0.056	0.167	0.444	0.078	0.431
XYw	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.000	0.002		0.107	-0.016	0.029	0.366	0.767
JY	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.001		-0.011	0.268	0.039	0.538
JX	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.001	0.001		0.074	0.129	0.692
QJ	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.000	0.002	0.000	0.001	0.001		0.476	**0.836**
Jap	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002		0.577
Ame	0.006	0.006	0.006	0.006	0.006	0.004	0.003	0.006	0.004	0.006	0.005	0.005	0.006	0.004	

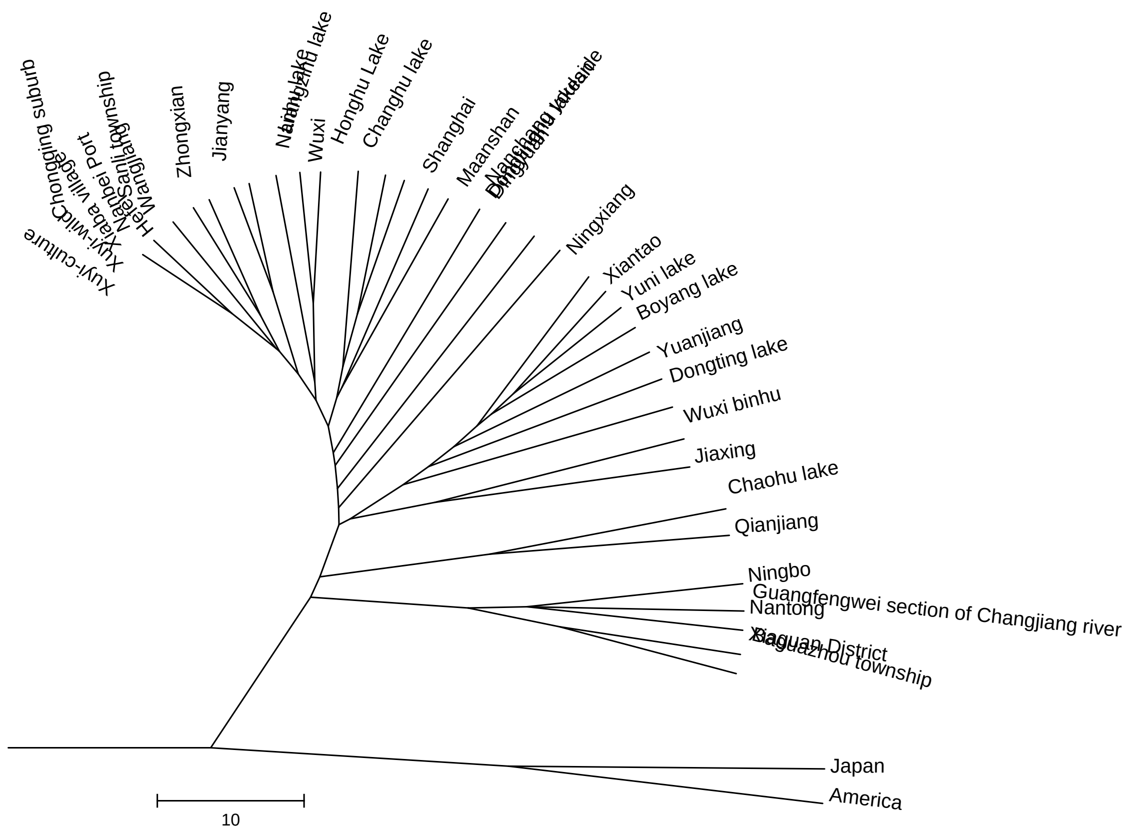

Figure 1. Cluster analysis of 37 red swamp crayfish populations.

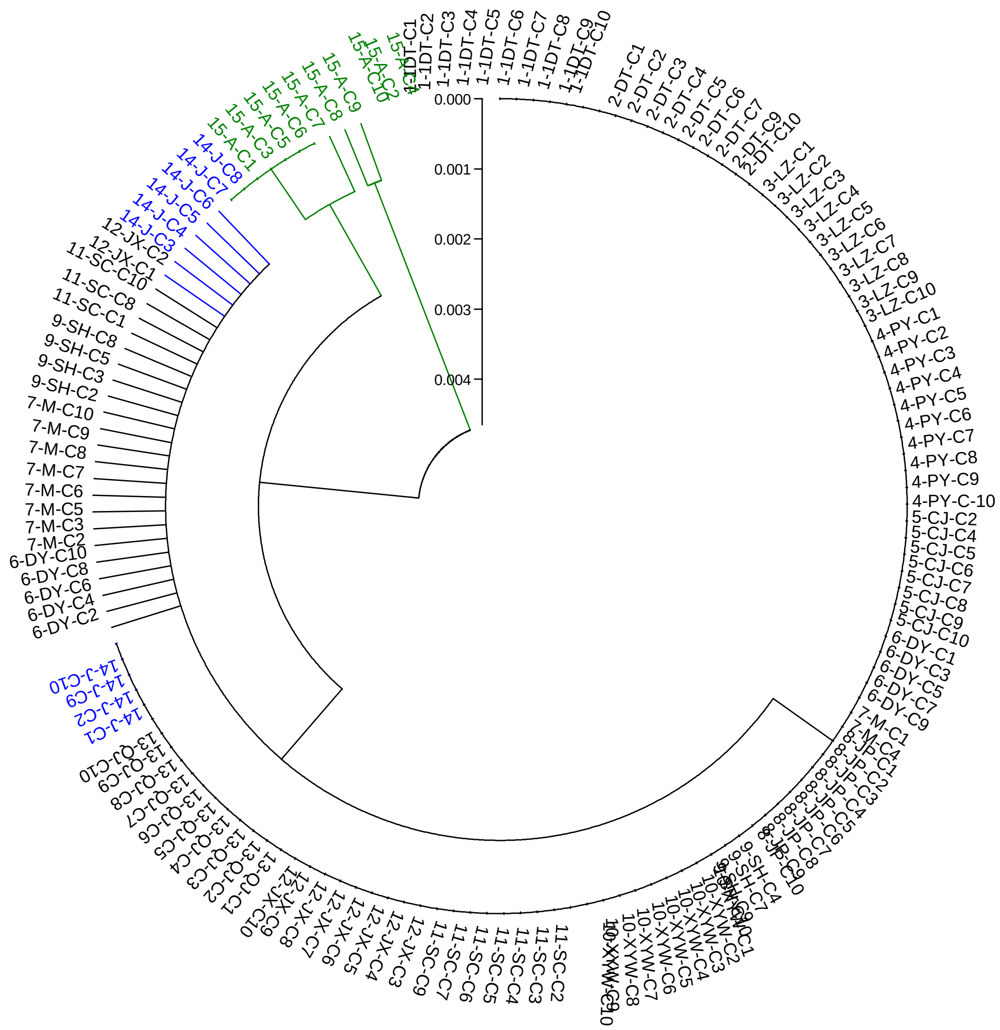

Figure 2. Neighbor-joining tree of COI sequences among 145 red swamp crayfish individuals.

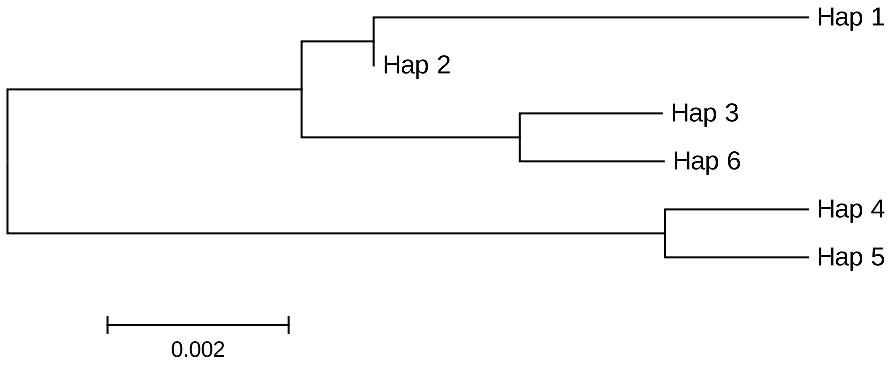

Figure 3. NJ dendrogram of six haplotypes in the 15 populations of *P. clarkii*.

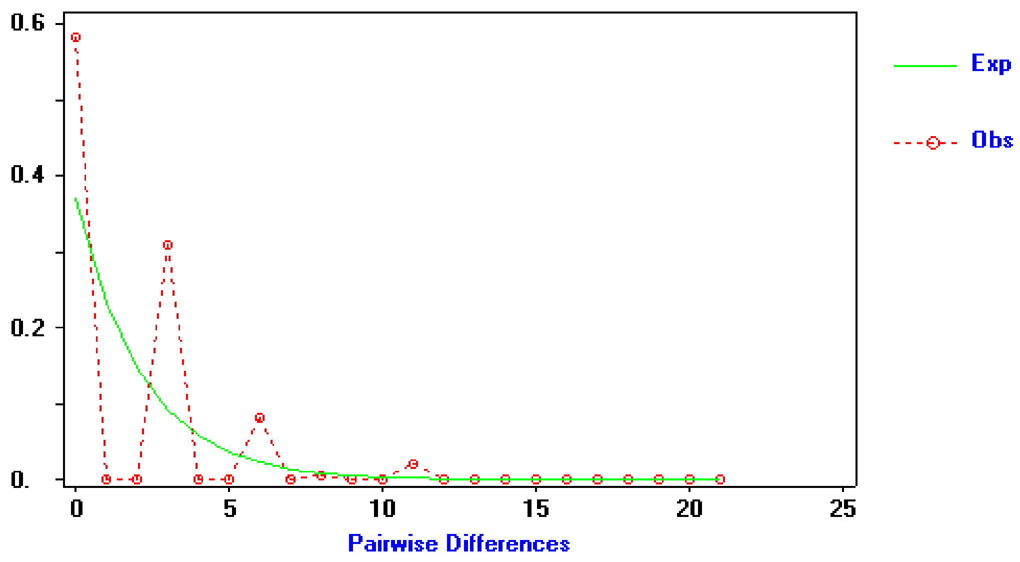

Figure 4. Population size changes analysis of mtDNA COI sequences.

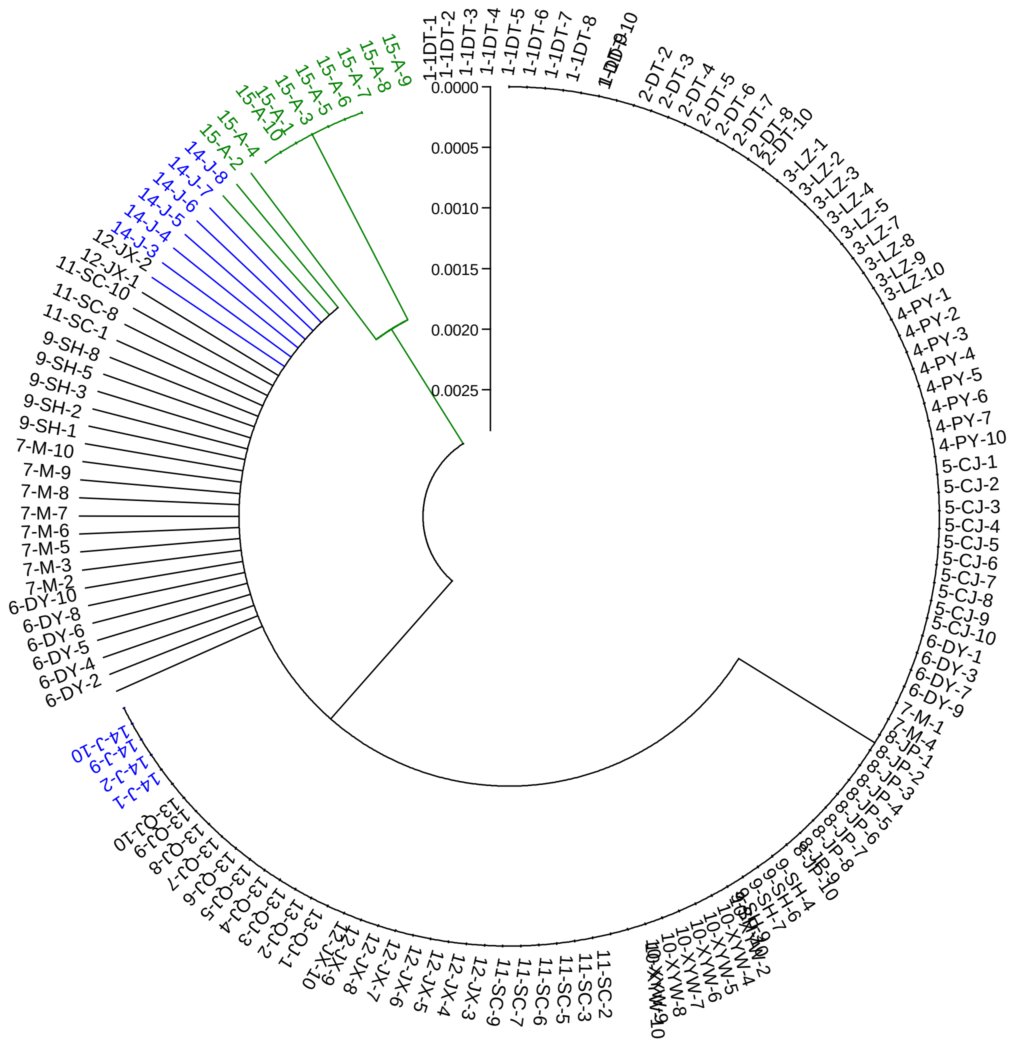

Figure 5. Neighbor-joining tree of 16SrRNA sequences among 142 red swamp crayfish individuals.

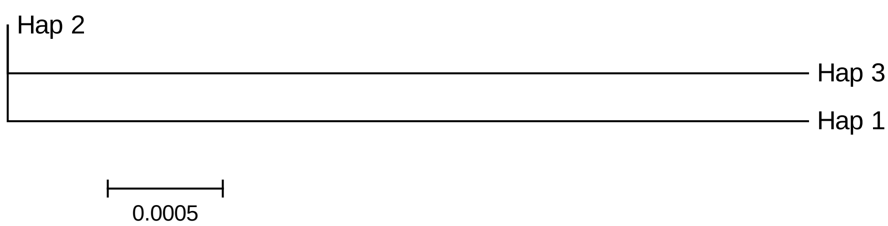

Figure 6. NJ dendrogram of three haplotypes in the 15 populations of *P. clarkii*.

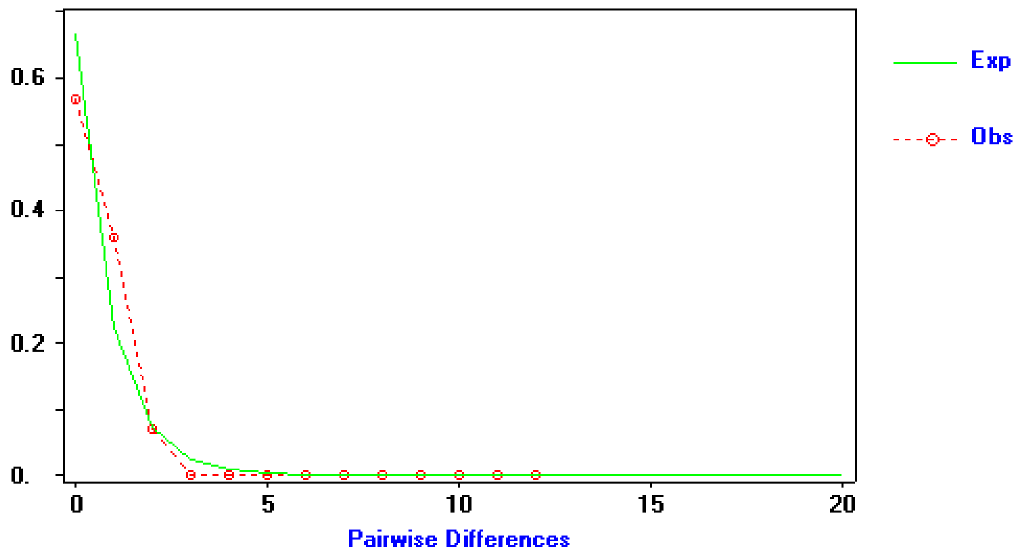

Figure 7. Population size changes analysis of mtDNA 16SrRNA sequences.

Appendix Table 1. Number of alleles (na*), mean number of effective alleles (ne*), observed heterozygosity (Ho), expected heterozygosity (He), Hardy-Weinberg departure value (D) and polymorphism information content (PIC), of 12 microsatellite loci in the *P. clarkii* population.

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	4	3.1736	1.0000	0.6921	0.4449	0.6304
	PCLG-03	25	14.2516	0.7660	0.9398	-0.1849	0.9257
	PCLG-04	12	8.9302	0.8542	0.8974	-0.0481	0.8780
	PCLG-07	10	6.0792	0.7917	0.8443	-0.0623	0.8179
	PCLG-09	15	7.3376	0.7917	0.8728	-0.0929	0.8491
	PCLG-10	8	4.5801	0.2609	0.7903	-0.6699	0.7478
SH	PCLG-13	6	2.5402	0.4792	0.6127	-0.2179	0.5616
	PCLG-15	14	7.3728	0.7917	0.8735	-0.0936	0.8504
	PCLG-17	13	6.5455	1.0000	0.8561	0.1681	0.8318
	PCLG-29	10	4.4869	0.8125	0.7853	0.0346	0.7493
	PCLG-32	14	6.8776	0.9792	0.8636	0.1339	0.8393
	PCLG-48	10	5.5787	0.9375	0.8294	0.1303	0.8019
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	7	4.8505	1.0000	0.8022	0.2466	0.7655
	PCLG-03	16	5.1854	0.4681	0.8158	-0.4262	0.7899
	PCLG-04	11	6.1935	0.2292	0.8474	-0.7295	0.8194
	PCLG-07	11	6.8065	0.5625	0.8621	-0.3475	0.8360
	PCLG-09	9	3.2961	0.3125	0.7039	-0.5560	0.6634
	PCLG-10	11	3.9097	0.4255	0.7522	-0.4343	0.7107
NB	PCLG-13	6	4.0421	0.3750	0.7605	-0.5069	0.7143
	PCLG-15	13	3.3488	0.5833	0.7088	-0.1771	0.6645
	PCLG-17	12	7.6800	0.6458	0.8789	-0.2652	0.8569
	PCLG-29	12	7.0127	0.8085	0.8666	-0.0670	0.8423
	PCLG-32	8	5.6264	0.9375	0.8309	0.1283	0.7976
	PCLG-48	9	6.3646	0.7083	0.8518	-0.1685	0.8250
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.7504	1.0000	0.7412	0.3492	0.6848
	PCLG-03	18	12.3754	0.7660	0.9291	-0.1755	0.9135
	PCLG-04	9	5.5990	0.4375	0.8300	-0.4729	0.7988
	PCLG-07	9	6.3123	0.7917	0.8504	-0.0690	0.8240
	PCLG-09	10	6.6237	0.5532	0.8582	-0.3554	0.8314
	PCLG-10	7	4.4824	0.3488	0.7860	-0.5562	0.7415

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
JX	PCLG-13	8	4.8549	0.3617	0.8026	-0.5493	0.7686
	PCLG-15	3	2.2058	0.3542	0.5524	-0.3588	0.4629
	PCLG-17	7	5.7889	0.9167	0.8360	0.0965	0.8049
	PCLG-29	10	4.9021	0.6875	0.8044	-0.1453	0.7771
	PCLG-32	8	5.4988	0.9583	0.8268	0.1590	0.7948
	PCLG-48	3	2.5540	0.7826	0.6151	0.2723	0.5267
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.2797	0.9792	0.7024	0.3941	0.6389
	PCLG-03	16	9.7627	0.6458	0.9070	-0.2880	0.8888
	PCLG-04	17	6.0632	0.8750	0.8439	0.0369	0.8238
	PCLG-07	8	3.5176	0.4375	0.7232	-0.3950	0.6816
	PCLG-09	11	6.1460	0.6364	0.8469	-0.2486	0.8186
	PCLG-10	6	3.4815	0.7872	0.7204	0.0927	0.6629
XYc	PCLG-13	6	4.0457	0.4583	0.7607	-0.3975	0.7139
	PCLG-15	8	4.2353	0.5625	0.7719	-0.2713	0.7273
	PCLG-17	7	4.4223	0.9375	0.7820	0.1988	0.7423
	PCLG-29	10	6.7657	0.8298	0.8614	-0.0367	0.8349
	PCLG-32	12	8.1385	0.8261	0.8868	-0.0684	0.8648
	PCLG-48	8	4.5900	0.9348	0.7907	0.1822	0.7496
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.7494	0.8750	0.7410	0.1808	0.6855
	PCLG-03	16	9.4000	0.7447	0.9032	-0.1755	0.8850
	PCLG-04	16	8.1967	0.9362	0.8874	0.0550	0.8667
	PCLG-07	9	3.2823	0.5319	0.7028	-0.2432	0.6443
	PCLG-09	11	7.3027	0.8958	0.8721	0.0272	0.8497
	PCLG-10	6	2.8989	0.5476	0.6629	-0.1739	0.5910
XYw	PCLG-13	8	3.7586	0.4792	0.7417	-0.3539	0.7082
	PCLG-15	5	2.8253	0.3542	0.6529	-0.4575	0.5783
	PCLG-17	8	4.7407	0.9375	0.7974	0.1757	0.7622
	PCLG-29	10	6.2604	0.7609	0.8495	-0.1043	0.8215
	PCLG-32	10	6.4215	0.8936	0.8534	0.0471	0.8273
	PCLG-48	12	6.5085	0.8542	0.8553	-0.0013	0.8302
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	2	1.9566	0.8511	0.4942	0.7222	0.3694
	PCLG-03	15	7.4128	0.5957	0.8744	-0.3187	0.8524

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-04	12	7.1221	0.3542	0.8686	-0.5922	0.8443
	PCLG-07	9	5.7814	0.4783	0.8361	-0.4279	0.8048
	PCLG-09	10	6.7106	0.6341	0.8615	-0.2640	0.8346
	PCLG-10	5	4.0459	0.8478	0.7611	0.1139	0.7105
WXb	PCLG-13	9	6.0393	0.2708	0.8432	-0.6788	0.8173
	PCLG-15	10	4.9073	0.6250	0.8046	-0.2232	0.7737
	PCLG-17	15	9.2903	0.9375	0.9018	0.0396	0.8829
	PCLG-29	11	6.5177	0.8542	0.8555	-0.0015	0.8296
	PCLG-32	10	7.1221	1.0000	0.8686	0.1513	0.8449
	PCLG-48	3	2.4881	0.2500	0.6044	-0.5864	0.5292
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	9	5.1086	0.9792	0.8127	0.2049	0.7802
	PCLG-03	14	5.2803	0.6222	0.8197	-0.2409	0.7937
	PCLG-04	11	6.0711	0.4375	0.8441	-0.4817	0.8164
	PCLG-07	10	6.5177	0.8125	0.8555	-0.0503	0.8288
	PCLG-09	10	5.2186	0.3333	0.8169	-0.5920	0.8346
	PCLG-10	6	3.2582	0.0667	0.7009	-0.9048	0.6407
NT	PCLG-13	6	4.0209	0.4167	0.7592	-0.4511	0.7121
	PCLG-15	13	5.4409	0.6383	0.8250	-0.2263	0.7988
	PCLG-17	11	7.1002	0.7917	0.8682	-0.0881	0.8439
	PCLG-29	12	6.6590	0.7292	0.8588	-0.1509	0.8325
	PCLG-32	11	6.3471	0.9167	0.8513	0.0768	0.8249
	PCLG-48	8	5.9355	0.6739	0.8407	-0.1984	0.8111
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	8	4.5036	0.9362	0.7863	0.1906	0.7458
	PCLG-03	17	12.2145	0.6136	0.9287	-0.3393	0.9124
	PCLG-04	8	4.5201	0.4667	0.7875	-0.4074	0.7442
	PCLG-07	9	3.8933	0.3696	0.7513	-0.5081	0.7052
	PCLG-09	7	4.6829	0.2500	0.7947	-0.6854	0.7545
	PCLG-10	9	4.7471	0.2093	0.7986	-0.7379	0.7620
XG	PCLG-13	7	4.9529	0.3830	0.8067	-0.5252	0.7690
	PCLG-15	6	2.6197	0.1667	0.6248	-0.7332	0.5508
	PCLG-17	15	9.4000	0.8085	0.9032	-0.1048	0.8847
	PCLG-29	8	5.2068	0.6250	0.8164	-0.2344	0.7811
	PCLG-32	12	6.7969	1.0000	0.8620	0.1601	0.8362
	PCLG-48	15	11.2132	0.8936	0.9206	-0.0293	0.9040

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	8	5.8108	0.9375	0.8366	0.1206	0.8059
	PCLG-03	22	15.8351	0.7292	0.9467	-0.2297	0.9332
	PCLG-04	14	7.1002	0.9167	0.8682	0.0559	0.8442
	PCLG-07	8	3.2428	0.6667	0.6989	-0.0461	0.6603
	PCLG-09	12	6.7665	0.9792	0.8612	0.1370	0.8355
	PCLG-10	7	3.6332	0.9362	0.7326	0.2779	0.6942
XBv	PCLG-13	6	4.1213	0.6596	0.7655	-0.1383	0.7195
	PCLG-15	5	2.2250	0.3542	0.5564	-0.3634	0.5125
	PCLG-17	10	7.0351	0.8750	0.8669	0.0093	0.8421
	PCLG-29	10	5.2118	0.8696	0.8170	0.0644	0.7829
	PCLG-32	10	5.6058	0.9583	0.8303	0.1542	0.7977
	PCLG-48	10	2.9903	0.5208	0.6726	-0.2257	0.6404
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	8	5.3769	0.9792	0.8226	0.1904	0.7892
	PCLG-03	21	12.2880	0.6250	0.9283	-0.3267	0.9131
	PCLG-04	12	6.8879	0.5417	0.8638	-0.3729	0.8409
	PCLG-07	7	4.0280	0.3125	0.7596	-0.5886	0.7151
	PCLG-09	6	4.3187	0.2500	0.7765	-0.6780	0.7304
	PCLG-10	13	7.5417	0.6875	0.8765	-0.2156	0.8539
BGt	PCLG-13	10	4.1106	0.4375	0.7647	-0.4279	0.7350
	PCLG-15	11	7.3493	0.7292	0.8730	-0.1647	0.8500
	PCLG-17	12	8.7078	0.6304	0.8949	-0.2956	0.8741
	PCLG-29	7	4.3761	0.4583	0.7796	-0.4121	0.7371
	PCLG-32	13	6.3475	0.9318	0.8521	0.0935	0.8257
	PCLG-48	13	9.4620	0.9583	0.9037	0.0604	0.8850
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	3	2.8533	1.0000	0.6564	0.5235	0.5744
	PCLG-03	22	11.1304	0.8958	0.9197	-0.0260	0.9035
	PCLG-04	14	7.6928	0.8542	0.8792	-0.0284	0.8575
	PCLG-07	8	5.1086	0.7500	0.8127	-0.0772	0.7762
	PCLG-09	7	4.8659	0.7292	0.8029	-0.0918	0.7648
	PCLG-10	10	5.6127	0.6875	0.8305	-0.1722	0.8005
WX	PCLG-13	6	2.9009	0.4681	0.6623	-0.2932	0.6017
	PCLG-15	10	2.2588	0.2500	0.5632	-0.5561	0.5356

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-17	9	4.0563	1.0000	0.7614	0.3134	0.7302
	PCLG-29	13	8.4706	1.0000	0.8912	0.1221	0.8704
	PCLG-32	9	5.6959	0.8542	0.8331	0.0253	0.8026
	PCLG-48	9	6.4628	0.8542	0.8542	0.0000	0.8261
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	6	3.4830	1.0000	0.7204	0.3881	0.6676
	PCLG-03	27	17.4569	0.5778	0.9533	-0.3939	0.9398
	PCLG-04	14	8.0984	0.7917	0.8857	-0.1061	0.8652
	PCLG-07	9	3.4870	0.5745	0.7209	-0.2031	0.6810
	PCLG-09	7	4.5359	0.7826	0.7881	-0.0070	0.7480
	PCLG-10	9	4.4702	0.9333	0.7850	0.1889	0.7474
WJ	PCLG-13	5	3.7403	1.0000	0.7404	0.3506	0.6885
	PCLG-15	9	4.2706	0.6458	0.7739	-0.1655	0.7319
	PCLG-17	15	10.1098	0.9574	0.9108	0.0512	0.8931
	PCLG-29	6	4.5942	0.9167	0.7906	0.1595	0.7481
	PCLG-32	10	6.6039	1.0000	0.8577	0.1659	0.8301
	PCLG-48	8	3.2823	0.5745	0.7028	-0.1826	0.6659
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	8	6.5085	1.0000	0.8553	0.1692	0.8274
	PCLG-03	21	13.5132	0.6250	0.9357	-0.3321	0.9214
	PCLG-04	14	7.9460	1.0000	0.8836	0.1317	0.8623
	PCLG-07	10	4.5988	0.4375	0.7908	-0.4468	0.7587
	PCLG-09	6	4.5877	0.3617	0.7904	-0.5424	0.7474
	PCLG-10	5	2.5430	0.7708	0.6132	0.2570	0.5513
MAS	PCLG-13	8	5.1601	0.2917	0.8147	-0.6420	0.7801
	PCLG-15	3	1.9567	0.0417	0.4941	-0.9156	0.3880
	PCLG-17	12	7.3143	1.0000	0.8724	0.1463	0.8496
	PCLG-29	7	2.9018	0.6250	0.6623	-0.0563	0.5973
	PCLG-32	11	5.9922	0.9167	0.8419	0.0888	0.8159
	PCLG-48	9	4.2082	0.6250	0.7704	-0.1887	0.7309
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	7	4.8814	1.0000	0.8035	0.2446	0.7635
	PCLG-03	22	10.7413	0.2500	0.9164	-0.7272	0.9005
	PCLG-04	11	6.7965	0.4792	0.8618	-0.4440	0.8362
	PCLG-07	9	3.3635	0.3958	0.7101	-0.4426	0.6591

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-09	5	3.2022	0.5625	0.6950	-0.1906	0.6390
	PCLG-10	7	2.6407	0.0833	0.6279	-0.8673	0.5742
CJr	PCLG-13	6	3.3056	0.4167	0.7048	-0.4088	0.6450
	PCLG-15	10	7.3610	0.6042	0.8732	-0.3081	0.8495
	PCLG-17	10	6.1704	0.7447	0.8469	-0.1207	0.8192
	PCLG-29	10	5.3581	0.3958	0.8219	-0.5184	0.7918
	PCLG-32	13	8.4810	1.0000	0.8918	0.1213	0.8708
	PCLG-48	10	8.4810	1.0000	0.8274	0.2086	0.7962
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.4083	0.9583	0.7140	0.3422	0.6532
	PCLG-03	17	9.8273	0.6667	0.9091	-0.2666	0.8898
	PCLG-04	17	10.3318	1.0000	0.9127	0.0957	0.8964
	PCLG-07	6	2.3679	0.4167	0.5838	-0.2862	0.5428
	PCLG-09	7	5.1030	0.8750	0.8125	0.0769	0.7761
	PCLG-10	3	1.7163	0.0000	0.4222	-1.0000	0.3603
CHL	PCLG-13	9	4.3308	0.6875	0.7772	-0.1154	0.7368
	PCLG-15	11	4.9655	0.5833	0.8070	-0.2772	0.7750
	PCLG-17	12	4.3761	0.9583	0.7796	0.2292	0.7393
	PCLG-29	12	7.7315	0.9167	0.8798	0.0419	0.8577
	PCLG-32	14	7.6418	1.0000	0.8783	0.1386	0.8568
	PCLG-48	12	7.0244	0.8333	0.8667	-0.0385	0.8429
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.2224	1.0000	0.6969	0.4349	0.6265
	PCLG-03	14	9.1610	0.5417	0.9002	-0.3982	0.8813
	PCLG-04	12	8.1413	0.8333	0.8864	-0.0599	0.8648
	PCLG-07	7	4.5851	0.3958	0.7901	-0.4991	0.7498
	PCLG-09	9	4.0671	0.6458	0.7621	-0.1526	0.7141
	PCLG-10	8	3.4621	1.0000	0.7186	0.3916	0.6650
HF	PCLG-13	6	1.9955	0.1277	0.5042	-0.7467	0.4765
	PCLG-15	9	4.2548	0.4583	0.7730	-0.4071	0.7381
	PCLG-17	9	2.9711	0.8936	0.6706	0.3325	0.6055
	PCLG-29	11	7.4638	0.8913	0.8755	0.0180	0.8540
	PCLG-32	6	3.8417	0.5957	0.7477	-0.2033	0.7039
	PCLG-48	9	5.3581	0.6042	0.8219	-0.2649	0.7866
	Loci	*na**	*ne**	Ho	He	D	PIC

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.8241	0.9583	0.7463	0.2841	0.6907
	PCLG-03	23	13.6331	0.5833	0.9364	-0.3771	0.9220
	PCLG-04	8	3.2821	0.9375	0.7026	0.3343	0.6487
	PCLG-07	10	3.9184	0.4583	0.7526	-0.3910	0.7129
	PCLG-09	7	4.4138	0.3125	0.7816	-0.6002	0.7399
	PCLG-10	6	3.1009	0.8125	0.6846	0.1868	0.6166
DY	PCLG-13	10	4.2548	0.3750	0.7730	-0.5149	0.7372
	PCLG-15	4	1.5479	0.3750	0.3577	0.0484	0.3296
	PCLG-17	8	5.0917	0.8125	0.8121	0.0005	0.7788
	PCLG-29	11	6.5829	0.8750	0.8570	0.0210	0.8315
	PCLG-32	8	5.2483	0.8750	0.8180	0.0697	0.7834
	PCLG-48	5	3.1648	0.1667	0.6912	-0.7588	0.6305
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	6	3.4414	0.8333	0.7169	0.1624	0.6570
	PCLG-03	23	14.0917	0.8542	0.9388	-0.0901	0.9249
	PCLG-04	13	5.8701	0.9375	0.8384	0.1182	0.8088
	PCLG-07	9	5.3457	0.6042	0.8215	-0.2645	0.7883
	PCLG-09	8	3.8919	0.4375	0.7509	-0.4174	0.7123
	PCLG-10	6	3.7131	0.4792	0.7384	-0.3510	0.6946
SLt	PCLG-13	6	3.1114	0.4375	0.6857	-0.3620	0.6265
	PCLG-15	4	1.8633	0.3333	0.4682	-0.2881	0.4275
	PCLG-17	13	6.9349	0.9111	0.8654	0.0528	0.8398
	PCLG-29	8	6.0792	0.7917	0.8443	-0.0623	0.8143
	PCLG-32	15	7.0016	0.8723	0.8664	0.0068	0.8424
	PCLG-48	13	7.8367	0.9167	0.8816	0.0398	0.8594
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	9	4.4223	0.9792	0.7820	0.2522	0.7396
	PCLG-03	20	11.2992	0.8723	0.9213	-0.0532	0.9052
	PCLG-04	18	7.1111	0.7708	0.8684	-0.1124	0.8470
	PCLG-07	8	3.8241	0.3958	0.7463	-0.4697	0.7030
	PCLG-09	6	3.7740	0.4375	0.7428	-0.4110	0.6904
	PCLG-10	10	4.9336	0.6250	0.8057	-0.2243	0.7715
NBp	PCLG-13	9	2.7494	0.4167	0.6430	-0.3519	0.6050
	PCLG-15	8	3.1692	0.4792	0.6917	-0.3072	0.6493
	PCLG-17	10	6.3297	1.0000	0.8509	0.1752	0.8247
	PCLG-29	8	5.3088	0.7292	0.8202	-0.1109	0.7869

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-32	13	7.7367	0.9130	0.8803	0.0371	0.8572
	PCLG-48	9	5.0361	0.7708	0.8099	-0.0483	0.7739
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.1118	1.0000	0.6861	0.4575	0.6155
	PCLG-03	20	7.6041	0.6596	0.8778	-0.2486	0.8564
	PCLG-04	18	9.1850	0.8298	0.9007	-0.0787	0.8821
	PCLG-07	7	3.6302	0.5319	0.7323	-0.2737	0.6765
	PCLG-09	10	4.1033	0.2292	0.7643	-0.7001	0.7314
	PCLG-10	7	3.5832	0.2500	0.7285	-0.6568	0.6856
PYL	PCLG-13	6	4.2314	0.4167	0.7717	-0.4600	0.7284
	PCLG-15	3	1.2072	0.1875	0.1735	0.0807	0.1601
	PCLG-17	7	5.4148	0.9167	0.8239	0.1126	0.7894
	PCLG-29	7	5.1717	0.7500	0.8151	-0.0799	0.7779
	PCLG-32	9	6.2976	0.6087	0.8505	-0.2843	0.8218
	PCLG-48	8	5.1314	0.6875	0.8136	-0.1550	0.7780
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	7	4.4393	1.0000	0.7829	0.2773	0.7408
	PCLG-03	16	10.3953	0.5106	0.9135	-0.4411	0.8962
	PCLG-04	14	10.6914	1.0000	0.9160	0.0917	0.8988
	PCLG-07	5	2.4792	0.2826	0.6032	-0.5315	0.5207
	PCLG-09	11	6.8496	0.6170	0.8632	-0.2852	0.8375
	PCLG-10	6	2.7378	0.9268	0.6426	0.4423	0.5661
NCyl	PCLG-13	8	3.4491	0.4375	0.7175	-0.3902	0.6800
	PCLG-15	7	3.2565	0.2708	0.7002	-0.6133	0.6449
	PCLG-17	14	10.2269	0.9787	0.9119	0.0733	0.8939
	PCLG-29	7	3.1030	0.6667	0.6849	-0.0266	0.6220
	PCLG-32	8	5.1396	0.4000	0.8145	-0.5089	0.7797
	PCLG-48	14	6.8571	1.0000	0.8632	0.1585	0.8393
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	7	4.0104	1.0000	0.7586	0.3182	0.7144
	PCLG-03	20	8.9825	0.6042	0.8980	-0.3272	0.8796
	PCLG-04	16	9.7834	0.9167	0.9072	0.0105	0.8897
	PCLG-07	6	3.7433	0.6875	0.7406	-0.0717	0.6950
	PCLG-09	11	7.8635	0.9792	0.8820	0.1102	0.8594
	PCLG-10	9	3.2844	0.5208	0.7029	-0.2591	0.6585

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
NHL	PCLG-13	7	4.9389	0.7917	0.8059	-0.0176	0.7711
	PCLG-15	11	4.2905	0.5833	0.7750	-0.2474	0.7466
	PCLG-17	12	7.8904	0.9167	0.8825	0.0388	0.8605
	PCLG-29	8	5.0205	0.7872	0.8094	-0.0274	0.7730
	PCLG-32	8	5.1486	0.8958	0.8143	0.1001	0.7790
	PCLG-48	14	6.5548	0.6458	0.8564	-0.2459	0.8326
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	6	4.5489	0.8958	0.7884	0.1362	0.7482
	PCLG-03	21	7.7707	0.5417	0.8805	-0.3848	0.8623
	PCLG-04	13	6.8166	0.9375	0.8623	0.0872	0.8398
	PCLG-07	8	4.8403	0.6667	0.8018	-0.1685	0.7627
	PCLG-09	10	6.6398	0.5417	0.8583	-0.3689	0.8319
	PCLG-10	9	3.9150	0.9375	0.7524	0.2460	0.7095
YNL	PCLG-13	10	7.1664	0.4792	0.8695	-0.4489	0.8443
	PCLG-15	11	4.4436	0.7500	0.7831	-0.0423	0.7423
	PCLG-17	13	9.0176	0.9583	0.8985	0.0666	0.8788
	PCLG-29	9	5.5186	0.8542	0.8274	0.0324	0.7984
	PCLG-32	10	6.0792	0.9792	0.8443	0.1598	0.8152
	PCLG-48	7	3.2821	0.2917	0.7026	-0.5848	0.6523
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	3	2.6995	0.9583	0.6362	0.5063	0.5585
	PCLG-03	20	9.6842	0.5217	0.9066	-0.4246	0.8890
	PCLG-04	13	7.9448	0.5833	0.8833	-0.3396	0.8621
	PCLG-07	8	4.1033	0.5000	0.7643	-0.3458	0.7219
	PCLG-09	9	6.2667	0.9149	0.8495	0.0770	0.8213
	PCLG-10	9	4.6126	0.8958	0.7914	0.1319	0.7616
XT	PCLG-13	7	5.3895	0.4792	0.8230	-0.4177	0.7889
	PCLG-15	8	4.0457	0.5000	0.7607	-0.3427	0.7235
	PCLG-17	6	3.4883	0.9375	0.7208	0.3006	0.6653
	PCLG-29	12	6.0393	0.8542	0.8432	0.0130	0.8150
	PCLG-32	8	5.7171	0.9792	0.8338	0.1744	0.8024
	PCLG-48	7	3.4212	0.3913	0.7155	-0.4531	0.6612
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	9	3.4936	0.7083	0.7213	-0.0180	0.6786
	PCLG-03	16	6.2693	0.2889	0.8499	-0.6601	0.8244

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-04	18	10.4253	0.8958	0.9136	-0.0195	0.8970
	PCLG-07	5	2.1235	0.4167	0.5346	-0.2205	0.4937
	PCLG-09	11	7.2466	0.6739	0.8715	-0.2267	0.8470
	PCLG-10	11	7.1029	0.3830	0.8685	-0.5590	0.8439
QJ	PCLG-13	4	3.4465	0.3750	0.7173	-0.4772	0.6568
	PCLG-15	7	5.2068	0.9583	0.8164	0.1738	0.7793
	PCLG-17	10	6.0711	1.0000	0.8441	0.1847	0.8152
	PCLG-29	10	3.3758	0.8125	0.7112	0.1424	0.6608
	PCLG-32	12	7.4323	0.7083	0.8746	-0.1901	0.8513
	PCLG-48	6	3.8400	0.8958	0.7474	0.1986	0.6943
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.3391	1.0000	0.7079	0.4126	0.6420
	PCLG-03	19	9.6463	0.7021	0.9060	-0.2251	0.8880
	PCLG-04	11	5.8551	0.2708	0.8379	-0.6768	0.8076
	PCLG-07	6	2.9811	0.4894	0.6717	-0.2714	0.6117
	PCLG-09	9	4.7554	0.6458	0.7980	-0.1907	0.7634
	PCLG-10	10	4.6762	0.8043	0.7948	0.0120	0.7650
LZL	PCLG-13	7	4.8150	0.4792	0.8007	-0.4015	0.7628
	PCLG-15	9	4.2627	0.6042	0.7735	-0.2189	0.7339
	PCLG-17	10	4.9126	0.9792	0.8048	0.2167	0.7668
	PCLG-29	13	9.1793	0.8750	0.9004	-0.0282	0.8811
	PCLG-32	12	9.5602	0.7083	0.9048	-0.2172	0.8859
	PCLG-48	5	3.6894	0.5000	0.7366	-0.3212	0.6817
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	4	2.8462	1.0000	0.6555	0.5256	0.5793
	PCLG-03	15	7.5571	0.1522	0.8772	-0.8265	0.8544
	PCLG-04	20	11.6263	0.8723	0.9238	-0.0557	0.9079
	PCLG-07	14	7.4323	0.5625	0.8746	-0.3568	0.8530
	PCLG-09	12	6.0157	0.9583	0.8425	0.1374	0.8156
	PCLG-10	13	8.0217	0.7674	0.8856	-0.1335	0.8629
HHL	PCLG-13	5	2.4602	0.8750	0.5998	0.4588	0.5160
	PCLG-15	8	2.5671	0.3125	0.6169	-0.4934	0.5834
	PCLG-17	12	6.1358	0.9167	0.8458	0.0838	0.8187
	PCLG-29	10	6.1114	0.9167	0.8452	0.0846	0.8181
	PCLG-32	8	6.2355	0.9375	0.8485	0.1049	0.8196
	PCLG-48	7	3.1911	0.6875	0.6939	-0.0092	0.6423

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	2.9307	0.9348	0.6660	0.4036	0.5890
	PCLG-03	15	7.6928	0.6042	0.8792	-0.3128	0.8571
	PCLG-04	14	5.1938	0.3953	0.8170	-0.5162	0.7924
	PCLG-07	5	2.3370	0.0889	0.5785	-0.8463	0.4800
	PCLG-09	8	5.2182	0.7174	0.8172	-0.1221	0.7836
	PCLG-10	12	7.0145	0.5909	0.8673	-0.3187	0.8430
CHL	PCLG-13	8	4.0457	0.4792	0.7607	-0.3701	0.7131
	PCLG-15	5	1.4495	0.2708	0.3134	-0.1359	0.2929
	PCLG-17	11	4.2686	0.8511	0.7740	0.0996	0.7342
	PCLG-29	11	5.0805	0.4583	0.8116	-0.4353	0.7829
	PCLG-32	10	5.6569	0.7660	0.8321	-0.0794	0.8022
	PCLG-48	11	6.7761	0.8936	0.8616	0.0371	0.8367
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	3.0396	0.9583	0.6781	0.4132	0.6089
	PCLG-03	9	4.0887	0.1667	0.7634	-0.7816	0.7152
	PCLG-04	10	7.5417	0.8333	0.8765	-0.0493	0.8533
	PCLG-07	7	5.2247	0.6957	0.8175	-0.1490	0.7816
	PCLG-09	8	4.2076	0.2766	0.7705	-0.6410	0.7366
	PCLG-10	10	4.6498	0.5417	0.7932	-0.3171	0.7570
YJ	PCLG-13	7	3.6600	0.2917	0.7344	-0.6028	0.6846
	PCLG-15	5	2.0719	0.4583	0.5228	-0.1234	0.4528
	PCLG-17	8	4.9585	0.6596	0.8069	-0.1826	0.7692
	PCLG-29	12	6.5641	0.8958	0.8566	0.0458	0.8321
	PCLG-32	8	5.5783	0.9362	0.8296	0.1285	0.7970
	PCLG-48	6	2.8166	0.4167	0.6518	-0.3607	0.6065
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	4	2.9501	0.8750	0.6680	0.3099	0.5983
	PCLG-03	12	4.8126	0.1489	0.8007	-0.8140	0.7671
	PCLG-04	19	9.3849	0.8750	0.9029	-0.0309	0.8851
	PCLG-07	7	4.6702	0.8085	0.7943	0.0179	0.7551
	PCLG-09	9	3.5558	0.4222	0.7268	-0.4191	0.6886
	PCLG-10	3	2.3815	0.3043	0.5865	-0.4812	0.5120
NX	PCLG-13	7	5.5186	0.3958	0.8274	-0.5216	0.7939
	PCLG-15	5	2.2143	0.3542	0.5542	-0.3609	0.4917

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-17	8	5.3832	0.8750	0.8228	0.0634	0.7886
	PCLG-29	8	3.4543	0.6458	0.7180	-0.1006	0.6628
	PCLG-32	8	5.8132	0.5870	0.8371	-0.2988	0.8051
	PCLG-48	6	2.7356	0.3913	0.6414	-0.3899	0.5847
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	6	3.7418	1.0000	0.7408	0.3499	0.6840
	PCLG-03	15	8.0742	0.5814	0.8865	-0.3442	0.8657
	PCLG-04	16	7.8472	0.7447	0.8819	-0.1556	0.8614
	PCLG-07	5	2.8872	0.7083	0.6605	0.0724	0.5967
	PCLG-09	5	3.9685	0.3333	0.7570	-0.5597	0.7041
	PCLG-10	7	3.5611	0.4375	0.7268	-0.3980	0.6778
DTL	PCLG-13	8	6.4538	0.4167	0.8539	-0.5120	0.8267
	PCLG-15	12	6.8674	0.7917	0.8634	-0.0830	0.8387
	PCLG-17	7	4.0907	0.9787	0.7637	0.2815	0.7164
	PCLG-29	9	5.0582	0.8750	0.8107	0.0793	0.7771
	PCLG-32	9	5.5385	0.8958	0.8281	0.0818	0.7980
	PCLG-48	5	2.8764	0.3750	0.6592	-0.4311	0.6037
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	7	3.9827	1.0000	0.7568	0.3214	0.7074
	PCLG-03	18	9.9525	0.4375	0.9090	-0.5187	0.8915
	PCLG-04	10	3.0157	0.4375	0.6754	-0.3522	0.6344
	PCLG-07	9	4.2627	0.7292	0.7735	-0.0573	0.7323
	PCLG-09	11	7.0244	0.9792	0.8667	0.1298	0.8417
	PCLG-10	8	4.8403	0.8958	0.8018	0.1172	0.7668
DTLs	PCLG-13	8	5.5252	0.3958	0.8276	-0.5217	0.7995
	PCLG-15	9	5.0526	0.6458	0.8105	-0.2032	0.7780
	PCLG-17	11	6.6494	1.0000	0.8586	0.1647	0.8349
	PCLG-29	12	8.8276	0.8958	0.8961	-0.0003	0.8758
	PCLG-32	12	7.4040	0.8000	0.8747	-0.0854	0.8506
	PCLG-48	8	3.9284	0.2292	0.7533	-0.6957	0.7073
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	5	2.4615	1.0000	0.6000	0.6667	0.5093
	PCLG-03	18	8.9825	0.8750	0.8980	-0.0256	0.8793
	PCLG-04	15	7.9723	0.9167	0.8838	0.0372	0.8627
	PCLG-07	12	5.5054	0.3958	0.8270	-0.5214	0.7974

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCLG-09	8	4.6651	0.4318	0.7947	-0.4567	0.7541
	PCLG-10	8	5.7672	0.3750	0.8353	-0.5511	0.8047
CQs	PCLG-13	6	3.6953	0.8750	0.7371	0.1871	0.6809
	PCLG-15	3	1.8893	0.0208	0.4757	-0.9563	0.3693
	PCLG-17	12	5.9305	0.9375	0.8401	0.1159	0.8119
	PCLG-29	6	4.9921	1.0000	0.8083	0.2372	0.7709
	PCLG-32	7	3.7858	0.9362	0.7438	0.2587	0.6952
	PCLG-48	8	2.9482	0.8542	0.6678	0.2791	0.6115
	Loci	*na*	*ne*	Ho	He	D	PIC
	PCL24	4	3.2337	0.9792	0.6980	0.4029	0.6356
	PCLG-03	9	3.8793	0.4222	0.7506	-0.4375	0.7159
	PCLG-04	8	4.1626	0.4583	0.7678	-0.4031	0.7296
	PCLG-07	6	3.3907	0.4167	0.7125	-0.4152	0.6576
	PCLG-09	6	4.2769	0.0213	0.7744	-0.9725	0.7281
	PCLG-10	7	3.7864	0.9792	0.7436	0.3168	0.6920
ZX	PCLG-13	7	4.5760	0.3750	0.7897	-0.5251	0.7502
	PCLG-15	2	1.2143	0.1522	0.1785	-0.1473	0.1609
	PCLG-17	5	3.1700	0.9565	0.6921	0.3820	0.6310
	PCLG-29	8	4.7982	0.8043	0.8003	0.0050	0.7599
	PCLG-32	7	3.9294	0.9783	0.7537	0.2980	0.7050
	PCLG-48	8	3.7586	0.3542	0.7417	-0.5224	0.6981
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	4	3.5149	1.0000	0.7230	0.3831	0.6632
	PCLG-03	15	6.9189	0.4792	0.8645	-0.4457	0.8425
	PCLG-04	9	4.8505	0.4792	0.8022	-0.4026	0.7690
	PCLG-07	6	3.2867	0.4375	0.7031	-0.3778	0.6458
	PCLG-09	7	4.6452	0.0417	0.7930	-0.9474	0.7529
	PCLG-10	5	4.1021	0.9574	0.7644	0.2525	0.7163
JY	PCLG-13	7	3.8336	0.3542	0.7469	-0.5258	0.7001
	PCLG-15	7	1.7588	0.3191	0.4361	-0.2683	0.4157
	PCLG-17	11	5.5855	1.0000	0.8296	0.2054	0.7999
	PCLG-29	8	4.8865	0.6875	0.8037	-0.1446	0.7666
	PCLG-32	8	4.9389	0.9792	0.8059	0.2150	0.7676
	PCLG-48	7	3.7664	0.5957	0.7424	-0.1976	0.6961
	Loci	*na**	*ne**	Ho	He	D	PIC

Pop.	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	18	11.8154	1.0000	0.9250	0.0811	0.9092
	PCLG-03	29	14.7759	0.7660	0.9423	-0.1871	0.9288
	PCLG-04	13	9.2530	0.4375	0.9013	-0.5146	0.8821
	PCLG-07	10	6.3911	0.5208	0.8524	-0.3890	0.8246
	PCLG-09	10	7.4805	0.5000	0.8754	-0.4288	0.8521
	PCLG-10	15	10.5442	0.5106	0.9149	-0.4419	0.8976
Jap	PCLG-13	7	3.3295	0.3750	0.7070	-0.4696	0.6680
	PC LG-15	17	8.7605	0.5625	0.8952	-0.3716	0.8767
	PCLG-17	11	9.3091	0.4792	0.9020	-0.4687	0.8827
	PCLG-29	12	9.2427	0.6170	0.9014	-0.3155	0.8819
	PCLG-32	16	11.9070	0.7917	0.9257	-0.1448	0.9098
	PCLG-48	14	9.6200	0.9792	0.9055	0.0814	0.8867
	Loci	*na**	*ne**	Ho	He	D	PIC
	PCL24	10	7.3880	0.6170	0.8739	-0.2940	0.8502
	PCLG-03	26	17.1301	0.7500	0.9515	-0.2118	0.9387
	PCLG-04	26	14.4000	0.6250	0.9404	-0.3354	0.9265
	PCLG-07	14	8.6292	0.7292	0.8934	-0.1838	0.8731
	PCLG-09	12	9.8837	0.7872	0.9085	-0.1335	0.8900
	PCLG-10	13	5.3644	0.4167	0.8221	-0.4931	0.8011
Ame	PCLG-13	6	4.5669	0.5417	0.7893	-0.3137	0.7482
	PCLG-15	14	8.9130	0.6042	0.8971	-0.3265	0.8780
	PCLG-17	17	8.5810	0.5625	0.8928	-0.3700	0.8724
	PCLG-29	10	5.9305	0.5833	0.8401	-0.3057	0.8103
	PCLG-32	14	8.0419	0.6250	0.8849	-0.2937	0.8640
	PCLG-48	13	6.9502	0.9167	0.8651	0.0596	0.8419

na: Observed number of alleles；ne：Effective number of alleles.

Ration Reduction, Integrated Multitrophic Aquaculture (Milkfish-Seaweed-Sea Cucumber) and Value-Added Products to Improve Incomes and Reduce the Ecological Footprint of Milkfish Culture in the Philippines

Mitigating Negative Environmental Impacts/Experiment/09MNE02NC

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ABSTRACT

In the Philippines, cage culture of milkfish in marine environments is increasing. The practice uses high stocking densities, with significantly greater inputs of artificial feeds which more often than not, have led to excessive feeding and consequently excessive nutrient loading in receiving waters, exacerbating problems with pollution. These could have contributed to occurrence of periodic fish kills in areas of marine milkfish culture clusters. In marine cage culture, about 80% of variable expenses are attributable to feed costs. Experiments were conducted to compare production characteristics of milkfish fed on alternate days versus those raised on daily feeding in marine cage culture. Fish were fed either daily or every other day using a reduced feed ration at 7.5% of fish biomass at the start of culture down to 3% of fish biomass towards harvest. We showed this ration level was as effective as the industry standard that begins at a rate of 10% average body weight. Morevover, we had previously found that milkfish reared in brackishwater ponds on an alternate day feeding scheme using the reduced ration level produced a 56% cost savings in feed with little impact on total yield relative to fish raised on a daily feeding protocol. In the present study, survival rates (~ 90%) were comparable between the control fish fed daily and groups fed on alternate days in marine cages. Similarly, total harvested biomass of fish in the alternate day and daily feeding groups was similar as was the harvest value, although fish on the alternate day feeding scheme grew slightly less. The amount of feed and the corresponding cost of feeds consumed were significantly lower in stocks that were fed on alternate days compared with those fed daily ($P < 0.05$). Feed conversion ratio (FCR) was lower in the alternate-day fed group (FCR = 2.46) relative to stocks fed daily (FCR = 3.59). Overall, the results demonstrate that feed costs can be reduced by around 32% in stocks fed on alternate days, which yields an estimated 20-25% improvement in production efficiency relative to raising animals on a daily feeding protocol. Hence, a significant costs savings with reduced impact of nutrient loading in the environment is likely to be realized for farmers who adopt an alternate day feeding scheme in raising milkfish in marine cages.

Although aquaculture is an important and increasingly intensive industry in the Philippines the concept of Integrated Multi-Trophic Aquaculture (IMTA) has not been systematically or widely practiced in aquaculture production. Although polyculture or integrated aquaculture has been practiced to some extent, the complementary trophic roles of various aquatic organisms in recycling nutrients and energy during the production cycle to contain the solid and liquid waste that pollute the aquatic environment has not been fully explored or utilized. Extensive aquaculture system where stocking density is low and the cultured species are totally dependent on the natural productivity of the culture environment for growth and sustenance is undoubtedly a sustainable practice but volume of harvest is low. On the other hand, intensive/semi-intensive aquaculture of a single species (monoculture) where stocking density is very high and relies heavily on high feed inputs, like in intensive shrimp culture, is not sustainable because of the release of enormous amounts of nutrient-rich wastes that pollute the coastal environment. Applying IMTA in intensive aquaculture systems will lessen its negative impact to the environment and with proper adjustments in the

stocking density and feed inputs, will make the practice sustainable. The potential is high for the application of IMTA in tropical aquaculture production systems to address two important global targets: increase aquaculture productivity for food security and protection of the aquatic culture environment.

The concept of IMTA was applied and tested in the current work on milkfish. For the trials in brackishwater ponds, six pond compartments with an area of 700 m^2 were stocked with milkfish fingerlings at a stocking density of 0.5 fish/m^2. Three ponds were stocked with sea cucumber at a density of 0.2 individuals/m^2. The seaweed *Gracilaria bailinae* was used as biofilter. Preliminary experiments were conducted and showed that high mortalities occur when sea cucumbers are stocked directly into the pond, with total mortality recorded within 1 week, which likely results from the silty-muddy substrate typical of brackishwater ponds in the Philippines. Culture of sea cucumber in cages set in ponds where milkfish are stocked was tested as an alternative. Survival of sea cucumber was very good (78-86%). The presence of sea cucumber or the sea cucumber cages likewise did not have any effect on the growth of milkfish in both weight and length. Thus, sea cucumber can produced as a value-added product in brackishwater pond production of milkfish. The seaweeds Gracilaria bailinae grown in canals between ponds initially showed good growth but later died off after alternating days of intense heat followed by days of heavy rains which lowered the salinity in the pond below 25 ppt.

For the trial in marine cages, the seaweed *Kappaphycus alvarezii* is used as biofilter. Milkfish fingerlings were randomly stocked in 6 units 5x5x3m cages at a density of 35 fish/m^3. Sea cucumbers were stocked under three of the cages. However, 100% mortality was observed during the 1st sampling (2 weeks). Trials on sulfide tolerance of sea cucumbers show that sea cucumbers cannot withstand the high sulfide environment under cages especially if the site has been used for mariculture operations for extended periods or as sulfide builds up with increasing biomass of stocks and hence increasing intensity of feeding. On the other hand, sea cucumbers seem to thrive in shallower marine pens thus co-culture of milkfish in pens needs to be tested. Although the feasibility of co-culture of milkfish and seaweeds in cages could not be determined in the present study due to outbreak of ice-ice disease resulting in mortalities in the seaweeds, *Kappaphycus alvarezii* grown in cages adjacent to the fish cages generally show good growth with increasing biomass of the cultured stocks and hence increasing intensity of feeding. These observations and information in the literature on the capacity of both *Gracilaria* and *Kappaphycus* to extract excess nutrients from the rearing water suggest that integrated culture of milkfish and seaweeds is feasible.

Information on the benefits of reduced feeding strategies as well as integrated and polyculture culture systems of species that are compatible with milkfish were disseminated through season-long training for community-based livelihood projects through a series of workshops. Skills development workshops were likewise conducted on milkfish processing and value-adding (e.g. deboning, production of flavoured deboned milkfish though smoking and use of various marinades) for women in major milkfish growing areas, as well as processing of seaweeds and preparation of various recipes using seaweeds for women in major seaweeds growing areas, respectively, as potential supplemental livelihood activities. The beneficiaries include 4 fishers' organizations from different coastal villages in Guimaras, fish and seaweeds farmers in Roxas (Capiz), Hamtik and Pandan (Antique) and womenfolk in Tigbauan (Iloilo).

INTRODUCTION

Milkfish (*Chanos chanos*) culture is the largest finfish aquaculture industry in the Philippines with total production of 250,000 metric tons annually (Table 1; DA-BAS 2011). As part of the Philippine government's food security and poverty alleviation programs, expansion of milkfish culture is a high priority (Rosario 2006) both to wean fishers off capture fisheries and to increase income of farmers and fishers alike, whose poverty levels are disproportionately high (Rivera et al. 2006). Milkfish continues to be a top aquaculture commodity of the Philippines primarily because it is easy to culture and can be grown in a wide range of environments. Milkfish thrives in freshwater, brackishwater, marine and even hypersaline habitats. Milkfish production is increasing rapidly with much of the production moving away from traditional culture in brackishwater ponds to fish cages in coastal marine waters, with a 98% increase in marine cage culture seen between 2005 and 2010 (see Table 1;

DA-BAS 2011). Cage culture of milkfish in coastal marine environments is done at higher densities and with significantly greater inputs of artificial feeds. Using this practice, however, has led to wastage of artificial feeds and excessive nutrient loading in receiving waters (Sumagaysay et al. 2004), exacerbating pollution problems and contributing to periodic fish kills in areas of intensive milkfish culture.

Currently, milkfish are fed daily at levels ranging from 10% to 4% of body weight (BW) depending on fish size (Coniza 2009). Based on our recent findings in phase I of the AquaFish CRSP, reducing the initial feeding rates from 10% BW to 7.5% BW produce similar growth rates to those seen in response to feeding at in milkfish grown in flow through seawater tanks (De Jesus-Ayson and Borski 2009; De Jesus-Ayson and Borski 2010). We also found that a > 50% cost savings in feeds is achieved when milkfish grown in brackishwater ponds are fed the reduced feeding rate on alternate days rather than the typical daily feeding protocol. Yield was not compromised with the alternate day feeding strategy. These results suggest that a similar cost savings might be found with milkfish raised in production scale sea cages. Hence, one objective of these studies was to evaluate if reducing feed inputs through alternate day feeding might provide a cost savings to milkfish production in sea cages.

The concept of Integrated Multi-Trophic Aquaculture (IMTA) systems uses various organisms having different feeding niches in a polyculture system. In temperate areas, IMTA is practiced by combining, in appropriate proportions, the cultivation of fed aquaculture species (salmon) with inorganic extractive aquaculture species (brown algae) and organic extractive aquaculture species (mussel). The aim of IMTA is to increase long-term sustainability and profitability per cultivation unit (not per species in isolation as is done in monoculture), as the wastes of one crop (fed species) are converted into fertilizer, food and energy for the other crops (extractive aquatic species), which can in turn be marketed for additional income. In this set up, all components in the culture system have an economic value and play key roles in the recycling processes of the system.

In modern coastal integrated mariculture, shellfish and seaweed are cultured in proximity to net pen fish culture (Troell et al. 1997). The red algae *Kappaphycus alvarezii* (Hayashi et al. 2008) and *Gracilaria heteroclada*, seaweed species widely distributed in the Philippines (Luhan et al. 2006) efficiently take up dissolved inorganic nitrogen in effluents from fish holding facilities. Seaweed production and quality are often enhanced in areas surrounding fish net pens than elsewhere (Troell et al. 1997). *K. alvarezii* is the most economically important seaweed in the Philippines. Monoculture of this seaweed in coastal waters of the country had generated high revenues to the small fishers. The farming of *K. alvarezii* in close proximity to fish cages has not been tried, though polyculture with grouper in cages was found to be economically feasible (Hurtado-Ponce 1992). On the other hand, the sea cucumber (*Holothuria scabra*) is an economically important species that is currently overexploited in the Philippines and worldwide. It feeds on detritus and algae and as such is an excellent species for polyculture with other farmed fauna (Purcell et al. 2006). This project will test the viability and economic feasibility of an integrated culture of milkfish, seaweeds and sea cucumber (e.g. sandfish) that is more environment-friendly and will bring added income to coastal communities.

Milkfish is traditionally traded in chilled or frozen form. However, there is a growing trend towards processing and production of value-added products. Marketing of milkfish outside the Philippines is constrained by the fact that it has numerous bones and spines embedded in its flesh. Women have been deboning milkfish for a long time. As part of a longterm training project, women will be trained on this and additional processing and value-adding techniques (e.g. deboning, smoking, marinating deboned milkfish in various flavors). Capacity building in this area will provide potential supplemental income to women.

OBJECTIVES

The general objective of this work is to reduce feed inputs and promote integrated culture for a more cost effective milkfish farming and reduce its environmental impacts while also providing additional income from seaweed and sea cucumber culture. The specific objectives are the following:

1. To compare alternate day feeding to the standard daily feeding on milkfish production in cages in coastal marine water[1]
2. To establish a more environmentally-friendly milkfish production system in cages or pens using the concept of integrated culture.
3. To evaluate the feasibility of co-culture of milkfish with seaweeds and sea cucumber in brackishwater ponds and in marine cages
4. To disseminate information on feeding rates and demonstrate the economic feasibility of integrated culture systems through season-long training for community-based livelihood projects.
5. To conduct skills development training workshops on milkfish processing and value-adding (e.g. deboning) for women in major milkfish growing areas as a potential supplemental livelihood opportunity.

METHODS, RESULTS AND DISCUSSION

1. Effect of alternate day feeding on marine cage culture of milkfish

For the trial in marine cages, milkfish fingerlings were randomly stocked in 6 units 5x5x3m cages at a density of 35 fish/m^3. Milkfish stocks in 3 of the cages were fed daily using SEAFDEC formulated feeds following the recommended daily feeding rate (see Table 2), while stocks in the 3 other cages were fed following the same daily feeding schedule but only on alternate days. The daily feeding rate recommended was based on our previous studies (De Jesus-Ayson and Borski 2009; De Jesus-Ayson and Borski 2010) where fish can be fed beginning at a rate of 7.5% average body weight versus the standard industry rate of 10% average body weight with little effect on growth in flow-through seawater tanks. Initial body measurements (body weight and body length) were taken at stocking and every two weeks thereafter until harvest in order to monitor growth as well as to adjust feeding ration. Difference in production parameters among treatment groups was analyzed by Students-t-Test.

Table 3 shows the growth of milkfish (changes in average body weight and body length) and Table 4 shows survival (%), the harvested biomass (kg) and estimated value of the production (PhP), the duration of culture, amount of feed consumed during the duration of culture and corresponding cost, and feed conversion ratio of milkfish grown under the different feeding regimen (daily feeding vs. alternate-day feeding). Survival of milkfish was comparable and averaged around 90% in stocks that were fed daily versus those fed on alternate days. Similarly, total harvested biomass of fish on the alternate day and daily feeding groups was similar. Although, not significantly different, the duration of culture for stocks fed on alternate days was slightly longer compared to stocks fed daily. This indicates that fish fed on alternate days grew at a slightly lower rate. The estimated value of the harvested biomass (in PhP) was similar among the two groups. On the other hand, the amount of feed consumed and the corresponding cost of feeds consumed were significantly higher in stocks that were fed daily compared with stocks fed on alternate days. This resulted in savings in feed cost of 32.94% in the alternate-day fed group. Feed conversion ratio (FCR) was higher in the daily fed group (FCR = 3.59) relative to stocks fed on alternate days (FCR = 2.46), but the difference was not statistically significant at the $P < 0.05$ level.

The results of this experiment on intensive culture of milkfish in marine cages are similar to that we previously reported for milkfish culture in brackish water ponds (De Jesus-Ayson and Borski 2009; De Jesus-Ayson and Borski 2010). Insofar as the FCR was lower and savings in feed costs was higher, the response to alternate day feeding in brackish water ponds was even better than that shown here in marine cages. The better response in brackish water ponds may likely be due to natural productivity available to fish as a food source in this environment. Nonetheless, the results shown here demonstrate that alternate day feeding strategies are an effective means to reduce feed costs in

[1] We initially proposed to reduce daily feed ration rate by an additional 1-2% in marine cage culture under this objective. However, we already established that we could reduce feed ration from Phase I of the CRSP project in milkfish held in flow-through seawater tanks (10% down to 7.5% average body weight; Investigation 07SFT03NC). Also, we had just completed studies at the end of Phase I, and found that an alternate day feeding regimen using the reduced feeding rate produced a cost savings of > 50% in milkfish cultured in brackishwater ponds. Therefore, we thought it would be more beneficial to test alternate day feeding in marine cage culture of milkfish using reduced feed ration already established as described herein rather than ascertain if a further reduction in daily feed ration could be beneficial as originally proposed. Indeed, we did find a 32% cost savings in feed when animals are fed on alternate days.

milkfish cultured in the marine environment. In highly intensive mariculture systems, feed cost can constitute up to 80% of production cost, and we show that an alternate day feeding strategy can reduce these costs by as much as 32%. This translates in around a 20-25% cost savings the total variable production costs for producing milkfish even with a slight delay in harvest time.

2. Evaluate the feasibility of co-culture of milkfish with seaweeds and sea cucumber in brackishwater ponds and in marine cages

Brackishwater Ponds

The experiment was designed to test the potential of milkfish, sea cucumber (*Holothuria scabra*) or sandfish and the seaweed, *Gracilariopsis bailinae*, for co-culture in an integrated system. First, preliminary experiments were conducted to test the compatibility of milkfish and sandfish in a co-culture system. A short experiment was conducted using juveniles of milkfish and juvenile sandfish kept together in an aquarium (5L) for one week. Behavior of both the milkfish and sandfish was observed for the duration of the experiment. No mortalities were recorded at the end of the observation period. The second trial was conducted in 250L fiberglass tanks provided with sand substrate, flow-through water and aeration. The experiment consisted of 3 treatments: sandfish and fish, fish only (control) and sandfish only (control). All treatments with fish used fish that were approximately 5 cm in size (8 fish per tank). Three size classes (small, medium and large) and three densities (4, 8 and 12 individuals per tank) of sandfish were tested in combination with fish. Fish were fed up to 10% of body weight of fish per day, spread over 3 rations. The sandfish only controls were fed the same amount as the average of the amount of feed given to the fish only control group. During each sampling (at the start of the experiment and every week for 4 weeks), measurements of fish weight and length, as well as length, width and weight of sandfish were taken. All fish were anaesthetized using 2-phenoxyethanol while sandfish were anaesthetized with 2% menthol. At the end of the experiment, both the fish and sandfish grew in length and body weight confirming the results of the previous experiment, and suggesting that milkfish and sandfish are suitable for polyculture (Zarate et al., unpublished observations).

An experiment on stocking density was also conducted. The experiment consisted of 4 treatments: 50g/m^2, 100g/m^2, 200g/m^2 and 300 g/m^2. Densities of 200g/m^2 and 300g/m^2 showed pronounced decline in growth even after the 1st week. 100g/m^2 and 50g/m^2 showed better overall growth but still showed declining growth after the 3rd week. These results indicate that stocking density of more than 200g/m^2 is not ideal for culture when depending on natural food alone. The decline in growth even for lower densities, further indicate the need for efficient feeding schemes after 2 or 4 weeks of culture of juvenile sandfish (Altamirano et al., unpublished observations).

Preliminary experiments were also conducted in tanks and in the field to test the substrate preference of *Holothuria scabra* in order to determine the range of habitats that will support its growth (Altamirano et al., unpublished observations). Results showed poor performance of sandfish in terms of growth and survival in sandy-muddy and silty-muddy substrates, while high survival were recorded in sandy substrates. A pond with sandy substrate showed best potential for sandfish culture (Altamirano et al., unpublished observations) in consonance with reports from Viet Nam where good production of sandfish cultured in marine ponds previously used for shrimp culture was observed (Nguyen Duy, unpublished observations). We directly stocked sandfish in brackish water milkfish ponds and observed high mortalities within 1 week, suggesting that most brackishwater ponds in the Philippines may not be suitable for sandfish because of the muddy substrate.

Culture of sandfish in cages set in ponds where milkfish are stocked was tested as an alternative. For the trials in brackishwater ponds, six pond compartments with an area of 700 m^2 were stocked with milkfish fingerlings at a stocking density of 0.5 fish/m^2. Milkfish stocks were fed following the recommended daily feeding schedule, but only on alternate days. Initial body measurements (body weight and body length) were taken at stocking and every two weeks thereafter until harvest (in 3 months) in order to monitor growth as well as to adjust feeding ration. Three ponds were stocked with sandfish in cages at a density of 0.2 individuals/m^2. During every other sampling of the milkfish stocks, the sandfish were counted to determine survival over time. The seaweed *Gracilaria bailinae* was used as biofilter and was grown in long lines in the canals surrounding the pond compartments. However, although the seaweeds grown in canals between ponds initially showed good growth, these later died off after alternating days of intense heat followed by days of heavy rains which lowered the salinity in the pond below 25 ppt.

Table 5 shows good survival of sandfish grown in cages set in brackish water ponds. The sandfish grew to an average of 64.39 $\pm$ 11.06 g, 62.58 $\pm$ 11.19 g, 66.0 $\pm$ 10.61 g for replicates 1, 2, and 3, respectively, when the milkfish were harvested. Sandfish grow at much slower rates than milkfish. Thus, in a milkfish + sandfish co-culture system, the sandfish can be grown to market size in the duration of culture of 2 crops of milkfish. In grow out culture in marine ponds as well as in a sea ranch, it takes more than 8 months to grow sandfish to reach a market size of about 300-400g, which can command a good price for the dried product. The sandfish were transferred to another pond with sea bass and pompano for on growing. The presence of sandfish or the sandfish cages likewise did not have any effect on the growth of milkfish as shown by similar trends in growth as indicated by changes in body weight and body length (Table 6).

Table 7 shows that total biomass harvested was comparable in the milkfish only group (90.71 $\pm$ 0.46 kg) and in the milkfish + sandfish group (99.58 $\pm$ 0.62 kg). Likewise, survival rates in the milkfish only group (90.57% $\pm$ 2.08) and milkfish + sandfish group (90.85% $\pm$ 0.62). Survival was generally high in sandfish until the 8th week (about 80%, Table 5) but dropped to about 60% on the 12th week (Table 5) after continuous heavy rains was experienced for several days and salinity fluctuations were recorded. Biomass of sandfish harvested per 2x2x1.5m cage was 5.47 $\pm$ 1.25 kg and can potentially be increased by increasing the number of cages set in the pond compartment.

Marine Cages

The experiment was designed to test the potential of milkfish, sandfish and the seaweed *Kappaphycus alvarezii* for co-culture in an integrated system. Preliminary experiments were designed to identify invertebrate species which may be used in an integrated multitrophic aquaculture (IMTA) system (MJHL Lebata-Ramos, personal communication). Sandfish *Holothuria scabra*, imbao *Anodontia philippiana* and Capiz shell or lampirong *Placuna placenta* were reared in either an open area without cage (no feeding), beneath a fish cage right after harvesting milkfish (no feeding) or beneath a fish cage rearing snapper *Lutjanus argentimaculatus* (with feeding). Growth and survival of sandfish, imbao and lampirong; as well as water quality parameters (temperature, salinity, pH, DO and sulfide) were monitored.

No mortality was observed in sandfish in all treatments until day 7. However, on day 28, 100% mortality was observed in the group reared under the snapper rearing cage, 25% in the group reared beneath a fish cage right after harvesting milkfish *Chanos chanos*, no feeding) and 3.33% in the group reared in an open area without cage (no feeding). Mortalities further increased on week 6 and on the week 8 100% mortality was observed in sandfish in all treatments. Capiz shells or lampirong reared beneath the snapper rearing cage and the milkfish cage right after harvest exhibited mortalities in the weeks following stocking and by week 16, all animals had died. On the other hand, survival of lampirong reared in the open area remained constant from week 8 to 22. In imbao, survival continued to drop in all three treatments and was very low after 22 weeks. Temperature (25.85-29.37°C), salinity (28.04-35.81 ppt), D.O. (0-6.5 ppm) and pH (8.02-8.14) did not significantly differ between treatments. Sulfide was significantly higher in the sediment under the snapper rearing cage (21.68±4.98 µmoles l^{-1}) compared with sulfide levels in sediments under the cage where milkfish used to be cultured (1.42 ± 0.24) and from the open area (1.20 ± 0.08), respectively (Kruska-Wallis Test, H=59.36, $p<0.001$). An increasing trend in sulfide levels was also observed in the sediment from under the snapper rearing cage. These results suggest that culture of these invertebrates immediately under the cages is not appropriate likely due to elevated sulfide levels in sediment (Lebata-Ramos et al., unpublished observations).

For the trial in marine cages we utilized the experiment outlined from Objective 1 that tested alternate day versus daily feeding on milkfish growout. Milkfish fingerlings were randomly stocked in 6 units 5x5x3m cages at a density of 35 fish/m^3. Milkfish stocks in 3 of the cages were fed daily following the recommended daily feeding schedule, while stocks in the 3 other cages were fed following the recommended daily feeding schedule but only on alternate days. Sandfish were stocked underneath three of the cages and seaweeds were grown in long lines in cages set adjacent to the milkfish cages. However, 100% mortality of sandfish was observed during the 1st sampling (2 weeks). Mortalities were previously thought to be due to predation. However, subsequent trials show that mortalities may be related to inability of sandfish to tolerate increasing levels of sulfide in the sediment under the cages as culture progresses or the high levels of sulfide in sediments in areas that have been used for aquaculture for a sustained period. On the other hand, sandfish seem to thrive in shallower marine pens thus co-culture of milkfish and sandfish in pens will be tested in the future.

Overall, these results show that tolerance of sandfish for sulfide is low. Sandfish is not able to survive for long in areas immediately adjacent to where mariculture activities are ongoing or have been sustained for long periods. Mortality of sandfish is correlated with increases in sulfide concentration in the sediment, which also tends to become more muddy as feed inputs increase with increasing biomass of stocks as occurs with cage culture of milkfish.

Kappaphycus alvarezii grown in cages adjacent to the milkfish cages initially showed good growth but later showed signs of ice-ice disease and exhibited stunting after alternating days of intense heat followed by days of heavy rains. While, the efficiency of *Kappaphycus alvarezii* to absorb excess nutrients from milkfish culture in cages could not be evaluated in the current experiment, better growth of the seaweed stocked in cages adjacent to the milkfish cages mid-way through the milkfish culture was reported (MRJ Luhan et al., unpublished observations). *Kappaphycus* has also been shown to grow better at the SEAFDEC Igang Marine Station when fish production in cages are on-going compared to times in the year when cages have no stocks or after harvest of stocks (Luhan et al., unpublished observations). *Kappaphycus alvarezii* was also reported to absorb excess nutrients from shrimp culture in tanks, resulting in better growth of the seaweed (HS Marcial, unpublished observations).

3. Demonstration of the economic feasibility of integrated culture systems and value-added processing of milkfish through season-long training for community-based livelihood projects

SEAFDEC AQD is currently implementing a project on cage culture of milkfish as a livelihood option for fisherfolks in coastal communities in Guimaras, Philippines under its program on Institutional Capacity Development for Sustainable Aquaculture. The over-all goal is to improve the socioeconomic conditions of fisherfolks in four (4) villages or barangays affected by a major oil spill in 2006 and to support the rehabilitation and ecological recovery program of the Province of Guimaras. The project also aims to develop the fisherfolk organizations (FOs) into viable and profitable business entities and responsible communities in the management of their coastal resources.

During the first phase, SEAFDEC AQD operated a demo farm for milkfish culture in marine cages in the mariculture facilities in its Igang Marine Station in Nueva Valencia, Guimaras. Milkfish farming was introduced as an additional livelihood option. At the same time, a “season-long” training was conducted covering various aspects of milkfish culture from cage design and construction, stocking, feeding management, on-farm feed preparation, disease management, harvesting, post-harvest processing and value adding, as well as marketing. A total of 120 fisherfolk from five FOs in 4 barangays of Nueva Valencia namely San Antonio, Igang, Magamay and Sto. Domingo participated in the different training modules. During the second phase, each of the 5 FOs (Samahan ng mga Mahihirap na Mangingisda ng San Antonio, Samahan ng mga Maliliit na Mangingisda ng San Antonio; Igang Small Fishermen’s Association; Magamay Small Fishermen’s Association, and Sto. Domingo Fisherfolks’ Association) in the 4 barangays was provided operational capital for the construction of a fish cage measuring 10X10X6 m for their culture trial and to serve both as a training/demonstration and production facility for the FOs. Milkfish fingerlings were stocked at 12,000 fishes per cage or at a stocking density of 20 fish/m^3 in December 2008. Culture was done for 6 months and the stocks were harvested from mid-June to July 2009. Income from the production runs was given to the respective FOs. The FOs are now operating their cages on their own, with technical assistance from SEAFDEC AQD.

Table 8 is a sample technical assumptions table for a cage culture operation for milkfish. Tables 9 and 10 show the actual operating expenses and cost and returns for a production run by the group of fisherfolks in Barangay San Antonio, in Nueva Valencia, Guimaras.

The price of milkfish is highly volatile and can change from P60 to P110 ex farm. Since production from the FO's cages is in relatively small volumes, they are highly vulnerable to fluctuation in prices. Although the prevailing price at harvest was relatively good (PhP91.22), there is plenty of room for improvement in terms of survival rate and most especially FCR.

The survival rate obtained for this particular run (86.18%) was below industry average of 90% or better. The FCR obtained was moderately high. Mortalities were experienced when stocks were left unfed for prolonged periods because of unavailability of feeds (mostly due to lack of funds for purchase of feeds). Towards this end of improving production and improving the prospects for the fisherfolks, the concepts of integrated culture and alternate day feeding strategies were introduced by the CRSP-SEAFDEC AQD group in a workshop held in November 2011 in the Nueva Valencia Gym. The Workshop consisted of two parts: a session for men with lectures on updates in milkfish mariculture (alternate day feeding strategies, polyculture systems, specifically milkfish and rabbitfish polyculture, integrated culture, and new feed formulation for milkfish) and a session for women with hands-on activities on seaweeds value addition and product development. There were twenty-five slots each for the sessions for males and females (five participants each from the 5 FOs). Twenty-three women and 17 men attended the workshops. To illustrate the potential of the concept of polyculture being introduced, sample technical assumptions and indicative cost and returns tables were shown for the co-culture of rabbitfish with milkfish and in marine cages (Table 11). Rabbitfish are a low-trophic omnivorous, grazing cultivar that utilizes feed wastage not consumed by milkfish and prevents cage net biofouling. It provides added income for milkfish farmers with no additional feed inputs.

Similar workshops were earlier organized for fish farmers in Roxas, Capiz and Hamtik, Antique (27 participants), and for seaweeds farmers looking for alternative aquaculture ventures in Pandan/Libertad (also in Antique; 28 participants). Additionally, 2 separate workshops were organized for groups of women in 2 barangays (Buyu-an and Parara) in Tigbauan, Iloilo (28 participants) on post-harvest processing and value addition in milkfish (deboning, marinated products, marketing techniques) to enhance income opportunities for fisherfolks. The workshops were met with considerable enthusiasm and our long-term training of the communities continues.

4. Additional Information Dissemination and Other Related Activities

Results of the alternate day feeding strategy have been disseminated in various local, national and regional fora through lectures in seminar workshops, training programs and conferences. In 3-4 May 2011, E.G. de Jesus-Ayson gave a lecture on marine fish culture in the light of environmental degradation and climate change incorporating results of the current milkfish project as well as results of work done in tilapia under the CRSP program during the Seminar Workshop on Fisheries and Aquaculture and Climate Change organized by the Bureau of Fisheries and Aquatic Resources Regional Office 2 in Tuguegarao, Cagayan as part of the activities lined up in celebration of Farmers' and Fisherfolks' month. F.G. Ayson likewise gave a lecture on breeding and seed production for aquaculture in relation to climate change in the same forum. Participants included 150 farmers, fisherfolks and local government officials. Similar lectures were also incorporated in the training course for trainers on marine fish hatchery and culture organized by SEAFDEC AQD for technical staff of all 7 Regional Fisheries Training Centers of the Bureau of Fisheries and Aquatic Resources held from 09 May to 24 June 2011. There were 21 participants in the course. Aside from the RFTC technical staff, there were also private participants from Iran (1) and the Philippines (1). Same lectures were included as well in the curriculum for the regular training course on marine fish hatchery and culture offered by SEAFDEC AQD annually with this year's course running from 20 June to 27 July 2011, with 11 participants from ASEAN member countries.

The alternate day feeding strategy for milkfish and tilapia were likewise included in the thematic paper on Maintaining the Integrity of the Environment Through Responsible Aquaculture and Adaptation to Climate Change presented by EG de Jesus-Ayson during the ASEAN-SEAFDEC Conference on Sustainable Fisheries for Food Security Towards 2020 - Fish for the People 2020: Adaptation to a Changing Environment (Session on Sustainable Aquaculture Development) held in Bangkok, Thailand from 13-17 June 2011 with over 500 participants from 29 countries.

During the months of April and May, on-the job trainees (OJTs) from various State Colleges and Universities (especially from Mindanao) assigned at the SEAFDEC AQD Marine Fish Hatchery and the Igang Marine Station assisted during samplings and were given informal lectures related to the project. They are as follows: Majella Alarcon, Cherry Lyn Elechicon, TJ Manalo, Girly Olangoy, Rethzel Seberias and Girlie Villanueva (Iloilo State College of Fisheries), Alvin Doroteo (University of Antique-Tibiao Campus) Renato Diaz, Jr. and Brillo Portevilla (Capiz State University), Mechell Advincula, Sitti Amina Hashim and Recil Palosero (Zamboanga State College of Marine Science and Technology), Carlos Angeles, Anwar Lingga and Yusof Saidali (Mindanao State University-Marawi Campus), and Junaldin Ibnosali (Mindanao State University-Tawi-tawi Campus).

CONCLUSIONS

Like that demonstrated for brackishwater ponds, alternate day feeding protocols reduce feed inputs without affecting production of milkfish in intensive marine cage systems. Feed costs were reduced by as much as 32% with an estimated 20-25% reduction in total variable production costs of milkfish in marine cages. This reduced feeding strategy can provide a substantial improvement in income for farmers while reducing environmental impacts associated with excessive nutrient inputs that are known to occur with intensive milkfish culture clusters in coastal environments.

The feasibility of growing sandfish in cages set in brackishwater ponds appears to be a viable alternative to direct stocking of sandfish in ponds which have a silty-muddy type of sediment that results in heavy to total mortalities. Culture of sandfish underneath marine cages or in areas within or immediately adjacent to milkfish mariculture areas was found to be not feasible because of the relatively high levels of sulfide in the sediment which the sandfish are not able to tolerate. However, farming of sandfish in pens or release of sandfish in seagrass beds in shallow areas surrounding mariculture areas may be a feasible alternative.

Although, the feasibility of co-culture of milkfish with seaweeds either in ponds (milkfish with *Gracilaria*) or in marine cages (milkfish with *Kappaphycus*) could not be demonstrated in the present experiments, due to extreme changes in weather, information from the literature as well as results from recent studies have demonstrated the efficiency of these seaweeds to absorb excess nutrients from brackishwater pond and marine cage culture systems, respectively. Hence, there is promise in the use of these seaweeds to mitigate the environmental impacts of milkfish farming.
Information on the benefits of reduced feeding strategies as well as integrated and polyculture culture systems of species that are compatible with milkfish were disseminated through season-long training for community-based livelihood projects through a series of workshops. Skills development workshops were likewise conducted on milkfish processing and value-adding (e.g. deboning, production of flavoured deboned milkfish though smoking and use of various marinades) for women in major milkfish growing areas, as well as processing of seaweeds and preparation of various recipes using seaweeds for women in major seaweeds growing areas, respectively, as potential supplemental livelihood activities. The beneficiaries include 4 fishers' organizations from different coastal villages in Guimaras, fish and seaweeds farmers in Roxas (Capiz), Hamtik and Pandan (Antique) and womenfolk in Tigbauan (Iloilo).

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Table 1. Milkfish production in metric tons (mt), 1996-2010

	1996	2000	2005	2010
Total Aquaculture Production	1,007,678	1,100,902	1,895,847	2,543,720
Total Milkfish Production	150,182	209,994	289,152	349,435
% of total aquaculture production	23	30	22	19
Brackish water ponds, pens	139,372	186,599	219,906	219,443
% of total milkfish production	93	89	76	63
Freshwater cages and pens	10,779	14,523	25,277	42,788
% of total milkfish production	7	7	9	12
Marine Cages and Pens	31	8,872	43,969	87,199
% of total milkfish production	0	4	15	25

Table 2. Feeding rate followed in experiment evaluating daily versus alternate day feeding of milkfish in marine cages.

Average Body Weight (grams)	Feeding Rate (% of Biomass)
< 50	7.5
50 to 100	6
100 to 150	5.5
150 to 200	5
200 to 250	4.5
250 to 300	4
300 to 350	3.5
350 to 400	3
400 to 500	2.5
>500	2

Table 3. Changes in body weight (grams) and body length (cm) of milkfish grown in triplicate in marine cages fed daily or on alternate days only. Values are means ± standard deviation, N=50

Days of Culture	Treatment A (Daily Feeding): Average Body Weight	Treatment A (Daily Feeding): Average Body Length	Treatment B (Alternate-Day Feeding): Average Body Weight	Treatment B (Alternate-Day Feeding): Average Body Length
Stocking	57.72 ± 18.79 68.51 ± 19.38 40.70 ± 8.35	15.14 ± 1.42 15.92 ± 1.40 13.58 ± 0.91	53.26 ± 22.29 56.09 ± 16.45 42.23 ± 11.44	14.71 ± 1.91 15.16 ± 1.43 13.87 ± 1.14
4 weeks	110.12 ± 26.13 107.02 ± 30.92 54.41 ± 13.86	18.67 ± 1.37 18.46 ± 1.68 15.07 ± 1.19	71.50 ± 22.45 86.77 ± 21.11 61.40 ± 14.33	16.27 ± 1.53 17.34 ± 1.35 15.73 ± 1.15
12 weeks	271.74 ± 66.09 237.13 ± 85.51 113.63 ± 30.98	23.13 ± 2.18 23.74 ± 2.50 19.12 ± 1.61	131.94 ± 48.93 162.36 ± 43.99 130.01 ± 34.48	19.82 ± 2.32 21.30 ± 1.85 19.96 ± 1.71
16 weeks	352.81 ± 81.60 399.81 ± 73.64 164.16 ± 36.04	26.95 ± 1.99 28.17 ± 1.97 21.71 ± 1.47	222.99 ± 50.26 245.94 ± 49.51 209.71 ± 63.86	23.49 ± 1.76 24.30 ± 1.65 22.91 ± 2.14
Harvest Time	Day 119 Day 126 207.28 ± 62.85 (Day 146)	23.11 ± 2.16	Day 138 286.63 ± 86.30 (Day 153) 318.41 ± 61.42 (Day 161)	25.48 ± 2.32 26.00 ± 1.71

Table 4. Survival (%) and production (kg) of milkfish grown in marine cages fed daily and on alternate days

Parameter	Fed Daily (Control)	Fed on alternate days
Biomass Harvested, Milkfish (kg)	681.5 844.0 585.0 Ave. = 704 $\pm$ 76[a]	724.0 793.5 528.5 Ave. = 682 $\pm$ 79[a]
Estimated Value (PhP)	71,400 86,780 56,220 Ave. = 71,4677 $\pm$ 8822[a]	84,035 79,350 46,750 Ave. = 70,045 $\pm$ 11726[a]
Survival Rate, Milkfish (%)	83.3 101.6 85.8 Ave. = 90.23 $\pm$ 5.7[a]	87.2 89.4 94.5 Ave. = 90.37 $\pm$ 2.2[a]
Days of Culture	119 126 146 Ave. = 130.3 $\pm$ 8.1[a]	138 153 161 Ave. = 150.7 $\pm$ 6.7[a]
Feed Consumed (kg)	2159.6 2667.4 2594.5 Ave. = 2474 $\pm$ 159[a]	1595.7 1914.3 1466.7 Ave. = 1659 $\pm$ 133[b]
Feed Conversion Ratio	3.17 3.16 4.44 Ave. = 3.59 $\pm$ 0.43[a]	2.20 2.41 2.78 Ave. = 2.46 $\pm$ 0.17[a]
Feed Cost (PhP)	53990.0 66685.0 64862.5 Ave. = 61846 $\pm$ 3963[a]	39892.5 47857.5 36667.5 Ave. = 41473 $\pm$ 3325[b]
Savings on Feed Cost (PhP)		**20373.33 (32.94%)**

Table 5. Survival of sandfish cultured with milkfish in cages in brackish water ponds

Days of Culture	Number of Individuals	Survival Rate (%)
Stocking	140 140 140	100 100 100
4 weeks	121 113 121	86.43 80.71 86.43
8 weeks	110 111 112	78.57 79.28 80.0
12 weeks	57 93 103	40.71 66.42 73.57

Table 6. Changes in body weight (grams) and body length (cm) of milkfish cultured with or without sandfish in brackish water ponds. Values are mean ± standard deviation, N = 50.

Days of Culture	Treatment A (w/out sandfish): Average Body Weight	Treatment A (w/out sandfish): Average Body Length	Treatment B (w/ sandfish): Average Body Weight	Treatment B (w/ sandfish): Average Body Length
Stocking	83.49 ± 31.72 73.88 ± 24.57 56.26 ± 14.43	17.31 ± 1.95 16.67 ± 1.72 15.48 ± 1.25	65.59 ± 26.48 61.63 ± 27.53 60.17 ± 25.67	15.95 ± 1.99 15.32 ± 2.38 15.59 ± 2.11
4 weeks	144.67 ± 57.32 124.51 ± 32.99 109.77 ± 20.21	20.51 ± 2.4 19.65 ± 2.30 19.22 ± 1.37	149.63 ± 52.45 141.58 ± 50 70 128.99 ± 38.36	20.74 ± 2.28 20.57 ± 2.18 20.09 ± 1.59
8 weeks	242.99 ± 50.50 229.48 ± 44.02 231.38 ± 30.50	24.69 ± 1.48 24.18 ± 1.50 24.40 ± 1.12	238.09 ± 39.59 259.65 ± 58.84 254.89 ±48.68	24.50 ± 1.32 25.11 ± 1.78 24.87 ± 1.52
12 weeks	315.98 ± 50.64 282.10 ± 46.92 290.60 ± 47.95	26.74 ± 1.35 25.82 ± 1.33 26.06 ± 1.29	322.30 ± 46.06 299.16 ± 49.29 317.96 ± 47.59	26.72 ± 1.23 26.29 ± 1.34 26.75 ± 1.27

Table 7. Survival (%) and production (kg) of milkfish cultured with or without sandfish. Values are means $\pm$ SE, N = 3.

Parameter	Milkfish only (Control)	Milkfish + Sandfish
Biomass Harvested, Milkfish (kg)	90.71 $\pm$ 0.46[a]	99.58 $\pm$ 0.62[a]
Survival Rate, Milkfish (%)	90.57 $\pm$ 2.08[a]	90.85 $\pm$ 0.62[a]
Biomass Harvested, Sandfish (kg)	NA	5.47 $\pm$ 1.25
Survival Rate, Sandfish (%)	NA	60.71 $\pm$ 14.57

Table 8. A sample technical assumptions table for a milkfish marine cage culture operation

Items	Value
Cage size	10X10X6m
Stocking Density	12,000 pc
Fingerling Size	5-6 inches
Days of Culture	6 months
Average Body Weight	450 grams
Survival Rate	90% (10,800 fish)
FCR (kg feeds/total biomass)	2.8
Total Biomass	4860 kg
Average Selling Price	P100/kg
Gross Income	PhP 486,000

Table 9. Actual operating expenses for a production run by the group of fisherfolks in Barangay San Antonio, in Nueva Valencia, Guimaras

A. Feeds	• **Quantity (kg)**	• **Unit Price**	• **Total Cost**
1. Starter Crumbles	1,500	27.3	40950
2. Starter Pellets	1,875	30.9	57937.5
3. Grower Pellets	5,700	25.9	147630
4. Finisher Pellets	3,750	25.5	95625
Subtotal	**12,825**	•	**342,142.5**
B. Fingerlings	• **12,000**	• 5	• **60,000**
C. Fuel	• **Quantity (Liters)**	• **Unit Price**	• **Total Cost**
1. Diesel Fuel	210	36	7560
2. Motor Oil	2	147	294
Subtotal	**212**	•	**7854**
TOTAL: OPERATING EXPENSES		•	**409,996.50**

Table 10. Costs and returns for a production run by the group of fisherfolks in Barangay San Antonio, in Nueva Valencia, Guimaras

Harvest Date	**Volume (kg)**	**Total Revenue (PhP)**	**Post Harvest Expenses**
June 22, 2009	1180.2	121,616	6289.36
June 30, 2009	2,225.90	187,030	5200
July 5, 2009	550.45	49,020	720
July 7, 2009	562.75	54,572.50	910
TOTAL	4,519.30	412,238.50	13,119.36
Operating Expenses			409,996.50
Overall Expenses (Post Harvest Expenses + Operating Expenses)			423,115.86
Net Income			-10,877.36

Table 11. Technical Assumptions for polyculture of milkfish and rabbitfish demonstrated through a workshop for fisherfolks and their organizations from 4 villages in Nueva Valencia, Guimaras.

Items	**Value**
Cage size	10X10X6m
Stocking Density	12,000 pc (milkfish) 4,000 (rabbitfish)
Fingerling Size	5-6 inches
Days of Culture	6 months
Cost of Fingerlings	P60,000 (milkfish) P20,000 (rabbitfish)
Average Body Weight	437 grams (milkfish) 200 grams (rabbitfish)
Survival Rate	86% (10,341 milkfish) 85% (3,280 rabbitfish)
FCR (kg feeds/total biomass)	2.8 (milkfish)
Total Biomass	4535.7 kg (milkfish) 656 kg (rabbitfish)
Average Selling Price	P100/kg (milkfish) P150/kg (rabbitfish)
Gross Income	P 453,570 (milkfish) P 98,400 (rabbitfish)
Overall Operating Expenses	P 423,115.86 (milkfish) P 20,000 (rabbitfish)
Net Income	**P 108,854.14**

Integrating Environmental Impacts, Productivity, and Profitability of Shrimp Aquaculture at the Farm-Scale as Means to Support Good Aquaculture Practices and Eco-Certification

Mitigating Negative Environmental Impacts/Study/09MNE03UM

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ABSTRACT

Nitrogen (N) and phosphorus (P) are key nutrients determining water quality in aquaculture. One component of this study employed mathematical modeling approach to examine the relationship among farm intensity, water management and nutrient dynamics over a complete production cycle. N dynamics included N input, assimilation, nitrification, and N loss through sedimentation, volatilization and discharge. P dynamics included P input, assimilation, and P loss through sedimentation and discharge. Models were calibrated for a commercial shrimp (*Litopenaeus vannamei*) farm in southern China. The models provided fairly good approximations to the observed values of total ammonia nitrogen (TAN), nitrate and nitrite (NO), chlorophyll (Chl) and total phosphorous (TP) ($R^2 = 0.94$). Model simulations indicated both stocking density and water exchange had significant impacts on concentrations of TAN, NO, TP and Chl. TAN, NO and TP levels increased with the intensification of the shrimp farming system. Chlorophyll concentration was mainly determined by water exchange. Nutrient loading was also increased with the intensification of the shrimp farming system. Approximately 701 kg N ha^{-1} $cycle^{-1}$ and 176 kg P ha^{-1} $cycle^{-1}$ were unutilized. Of them, 120 kg N ha^{-1} $cycle^{-1}$ in dissolved form (TAN+NO) and 62 kg P ha^{-1} $cycle^{-1}$ were discharged through regular daily water exchange. Moderate stocking density and reduced water exchange would be one solution to minimize environmental impacts of pond effluents and meanwhile maintain shrimp production. Future research should continue and concentrate on optimizing shrimp farming system to make the shrimp farming industry more sustainable.

Chinese shrimp farming is a diverse industry operated at different levels of intensity with different management strategies. The second component of this study aimed to capture farm diversity at regional level to evaluate system profitability for more sustainable development of shrimp farming. Risk of disease outbreak on farm economy and potential of implementing effluent treatment and participating certification programs were explored. Technical and economical characteristics of 100 farms in Hainan Province, China were surveyed during summer 2010 using an in-depth questionnaire. Multivariate analyses including factor and cluster analysis were employed to identify four farming systems by farm intensity, diversity, and labor origin. The categories were: intensive family and intensive commercial farms, semi-intensive and polyculture farms. Differences in management strategies affected farm profitability. Intensive family and commercial farms showed the highest profitability, followed by polyculture and semi-intensive farms. Influential factors to farm profitability were stocking density, aeration rate and feeding rate. Farm size and water exchange rate showed insignificant impacts on farm economy. Disease outbreak showed highest influence for intensive family and commercial farms, and least impacts for polyculture farms. In general, farm operators were not interested in establishing effluent treatment plans or participating in certification programs. Community members believed their quality of life was improved by shrimp farming in the region.

INTRODUCTION

Intensification of the shrimp farming industry has generated global concerns over its negative environmental impacts caused by unsustainable management (Casillas-Hernández et al., 2006; Naylor et al., 2000). Farm intensification uses more feed inputs, thus requiring more frequent flushing with new water and generating substantial amounts of waste materials such as nutrients, organic matter and suspended solids (Crab et al., 2007). Discharge of untreated pond effluents enriched in nutrients and organic matter may significantly contribute to high organic matter loads and thus cause eutrophication, hypoxia and turbidity in the receiving environment (Thomas et al., 2010). Effluent discharge also has potential of spreading disease pathogens and causing cross-farm pollution. Inefficient use of costly nutrients can also reduce farm profitability (Jackson et al., 2003). One of the major challenges facing sustainable development of shrimp farming is maintaining optimum water quality and minimizing nutrient loading. Good management practices are effective to reduce occurrence of water quality problems and achieve successful shrimp production. This urges on us the need to understanding nutrient dynamics and the implications of management in shrimp ponds.

Intensive shrimp farming in China is typically a flow-through system with high water exchange and aeration rates as means to maintain water quality at satisfactory levels for the crop. Most intensive farms operate in lined earthen ponds with average size of 0.2-0.4 ha. Farmers usually culture 2-3 crops per year in Southern China. According to our survey, intensive shrimp farming in southern China shows wide variation in management practices, with stocking densities from 75-180 post larvae (PL) m^{-2} and daily water exchange rates from 1-50% day^{-1}. Unit production ranges from 5-13 tonnes ha^{-1} $cycle^{-1}$, with feed conversion ratio (FCR) from 1.5-2.2.

Nitrogen (N) and phosphorous (P) components play important roles in water quality management. N is usually the key element limiting algal growth in marine aquaculture, while P is the critical nutrient in freshwater aquaculture (Goldman et al., 1974). Both of them can cause eutrophication problems when carrying capacity of a water body is exceeded. Previous studies on nutrient budgets in shrimp ponds indicated that the primary source of nutrients was feed, and the major sinks for nutrients were harvested shrimp, sediment and effluents (Casillas-Hernández et al., 2006; Funge-Smith and Briggs, 1998; Jackson et al., 2003; Xia et al., 2004). N and P inputs that are not incorporated into shrimp biomass are taken up by phytoplankton, settle as sediment, or are discharged with effluents. Different management practices can significantly affect water quality and thus shrimp growth in the pond. Modeling nutrient dynamics under different management scenarios is a fundamental step for understanding of feed utilization efficiency, changes in water quality and biogeochemical processes. Investigating the effects of farm intensity and water management on nutrient dynamics can help develop potential solutions to decrease nutrient loading and thus reduce environmental impacts of shrimp farms.

Mathematical modeling has been proven as a useful tool for a better understanding of nutrient dynamics in complex systems (Burford and Lorenzen, 2004; Jimenez-Montealegre et al., 2002). Optimization approaches are usually used to find parameters which best fit the model to observed data (Munoz-Tamayo et al., 2009). Several studies employed mathematical modeling to evaluate N dynamics in intensive shrimp ponds (Burford and Lorenzen, 2004; Lorenzen et al., 1997; Montoya et al., 1999). However, the dynamics of P flow in intensive shrimp ponds have not received much attention (Montoya et al., 2000).

Converted from traditional agriculture systems, Chinese shrimp farming is a diverse industry operated at different levels of intensity. The main cultured species in China is white-leg shrimp (*Litopenaeus vannamei*) due to its high economic value, low risk of disease, and short culture duration to reach market size. There are currently about 14,000 shrimp farms in China (Biao and Kaijin, 2007), usually classified by farm intensity and stocking density. This conceptual classification technique can often be misleading compared to other aquaculture systems such as tilapia farming. For example, semi-intensive tilapia farming relies only on natural food, while shrimp in semi-intensive farms feed on both natural food and commercial feed but are usually stocked at a much lower density than in intensive farms. Shrimp farming systems are generally more intensified than most of fish farming systems.

Identification of farm typology is an efficient method to summarize the diversity of production systems (Righi et al., 2011). Understanding the diversity of shrimp farming systems based on empirical classification and subsequently comparing their economic performance can facilitate decision-making for sustainable development. A multivariate technique, factor analysis, is usually employed to reduce the large number of initial variables to a limited number of significant factors. Such factors can then be elaborated by hierarchical or non-hierarchical clustering techniques to identify interesting farm groupings (Righi et al., 2011). Studies have employed these techniques to study characteristics of semi-intensive shrimp farming in Mexico (Ponce-Palafox et al., 2011), the typology of Asian carp (Michielsens et al., 2002), and Thai shrimp production systems (Joffre and Bosma, 2009). Agronomic and technical characteristics such as farming environment, farm size and level of intensification (Lazard et al., 2010) may be used to determine the typology of shrimp farming.

Economic analysis can provide a systematic evaluation of aquaculture activities, which in turn can lead to better management strategies towards economic sustainability. Economic sustainability of any farming system is examined by its profitability based on cost and profit analysis. Primary costs of shrimp farming include start-up investment and annual operating costs (Shang, 1981). Start-up investment costs include farm construction and equipment such as pumps and aerators. Annual operating costs can be further divided into fixed and variable costs. Fixed costs include land lease, depreciation, and maintenance of equipment. Variable costs include feed, seed, electricity, labor and other uses such as transportation. Farming systems with different management technologies may have significant differences in economic performance.

Risk of disease outbreak has a substantially negative influence on farm economy and has become a major concern in the shrimp industry. Disease outbreak can cause partial or massive crop failure, which can largely challenge sustaining production and affect profitability of the sector. Disease almost led to collapse of the shrimp industry in the 1990s in many Asian countries (Bhattacharya and Ninan, 2011). Over-intensification and many improper management practices such as discharge of untreated effluents into receiving waters make the current shrimp industry vulnerable to disease outbreak. Approximately 43 billion metric tons of untreated effluents from shrimp aquaculture discharge into the ambient aquatic environment each year in China (Biao and Kaijin, 2007). Discharge of untreated effluents may contaminate water quality and spread disease to adjacent farms. Few studies have evaluated the potential of adopting effluent treatment by shrimp farmers. Third-party certification is now viewed as a market-based tool for promoting better management practices and guaranteeing a price premium for maintaining good practice standards. Certification is an important factor affecting market price and thus farm profitability. Certification programs have not been widely established in China. The potential of shrimp farms in China to implement good management practices and participate in certification programs needs to be explored.

Quality of life is also considered as an important indicator of sustainability (Flores and Sarandón 2004). Many studies have discussed farmers' quality of life in sectors of aquaculture (Pomeroy et al. 2006), forestry (Kusel 2001) and livestock (Marker et al. 2005). Currently, few studies have yet applied a rigorous research of the role of shrimp aquaculture in tropical farmers' quality of life.

The objectives of the study were: 1) characterize N and P dynamics in intensive shrimp farming over a complete production cycle, 2) evaluate the diversity of shrimp farms towards its typology using multivariate techniques, 3) compare the identified farming systems for their technical characteristics and financial performance to determine the most profitable system, 4) assess key management practices that had significant impacts on farm profitability, 5) model risk of disease outbreak on farm economy, 6) investigate potential of implementing effluent treatment and participating certification programs by shrimp farmers, 7) evaluate change in quality of life caused by shrimp farming from perspectives of shrimp farmers and other villagers. Our results can provide practical insights for decision- or policy-making in order to promote good management practices towards economic sustainability.

METHODS

Data collection

During April-July 2010, field sampling for nutrient dynamic modeling was conducted in a commercial intensive shrimp farm in Hainan Province, China. Three lined earthen ponds (0.33 ha each) of the farm were selected and monitored as replicates over a complete production cycle. The ponds shared the same intensive culture practices. They were stocked with white shrimp *Litopenaeus vannamei* at 135 PL m^{-2}. Harvest occurred after about 100 rearing days. Shrimp were fed three times daily with local commercial feed which included 42% crude protein using feeding trays to determine actual consumption rates. Feeding rates were based on shrimp population density, with small adjustment daily to actual consumption in the feeding trays. Commercial pelleted feed was the only food applied and no fertilizer was added. Daily water exchange was implemented at rates of 1%, 5%, and 10% of the total pond water volume in the first, second and third month onwards, respectively. Effluents were continuously discharged into the receiving environment over the production cycle. Each pond was equipped with a paddlewheel at each pond corner and one in the pond center. Mechanical aeration was regularly used in each pond for a total (all paddle wheel time combined) of 20, 48 and 100 hours per day in the first, second and third month onwards, respectively. Thus water column was assumed to be well mixed so that a single sampling at any location was representative of the whole pond. A subsample of 50 shrimp was removed at biweekly intervals from each pond to assess shrimp growth throughout the culture period. Pond records were used to quantify total amounts of commercial feed added. At the end of the rearing cycle, shrimp were harvested by complete draining of the ponds and weighed to determine gross yield. Average production of the three ponds was 10.3 tonnes ha^{-1} $cycle^{-1}$ and FCR was approximately 1.7.

Water samples were collected weekly (sampling time at 1200-1300 h) at 20-30 cm below water surface from day 1 to harvest. Temperature, salinity, dissolved oxygen, pH, and turbidity were measured in the field using a portable water quality meter (Model WQC-24, Xebex International, Ltd.). Water samples were collected near the discharge gates and stored in clean plastic bottles, kept on ice, and transported to the laboratory for analysis immediately.

Total ammonia-N (TAN), nitrite-N (NO_2), nitrate-N (NO_3), total Kjeldahl nitrogen (TN), dissolved reactive phosphorous (DRP), total phosphorous (TP), Chlorophyll α (Chl) and total suspended solids (TSS) were analyzed. The determination of TAN, NO_2, NO_3, DRP, Chl and TSS were conducted according to standard methods (Strickland and Parsons, 1972; APHA, 1989). TN and TP was analyzed using a persulfate digestion method (Valderrama, 1981). Water quality data from the three ponds were treated as replicates, and mean values were used for model calibration. Shrimp carcass and shrimp feed were also analyzed for composition of N and P following standard methods (AOAC, 1980).

Data for socio-economic analysis was obtained during an in-depth survey in Hainan province, China from June to August 2010 with assistance of partners from Hainan University. The questionnaire for the survey was tested in the field and then improved in response to feedback before start of the general survey. The survey collected information on farm characteristics such as farm area, pond size, labor, feed use, farming techniques such as stocking density and aeration rate, production, costs, profits, disease outbreak, production problems, and farmers' attitudes on effluent treatment and certification. Based on farmers' conceptual classification, there were four main types of shrimp farming systems in Southern China. We randomly selected 25 shrimp farms from each type. A total of 100 shrimp farms differing in level of intensity, diversity, and labor origin were randomly sampled. For each survey site, farm owners or head managers were interviewed. Facility records were used for verification to reduce possible errors.

A range of economic indicators was selected and calculated using definitions following Shang (1981) and Joffre and Bosma (2009). Feed conversion ratio (FCR) represents the quantity of feed fed to grow one kg of aquaculture product. Labor productivity was calculated as total shrimp production in kg/ha per laborer day. Contracted labor hired on monthly or yearly basis was differentiated from occasional workers hired on a daily or weekly basis. Capital use efficiency was calculated as the net ratio of gross returns to capital costs (Michielsens et al., 2002). Capital cost included land, depreciation of equipment and operational costs (Michielsens et al., 2002).

Nutrient dynamic modeling

Conceptual models of N and P dynamics in intensive shrimp ponds were developed based on previous models (Lorenzen *et al.*, 1997; Burford and Lorenzen, 2004). Feed was considered as the only source of N and P input. Other sources such as inflow and precipitation were neglected due to their small contribution of less than 5% of the total (Lorenzen *et al.*, 1997).

Models were calibrated using our observed data. Following Lorenzen et al. (1997) and Burford and Lorenzen (2004), management parameters were derived directly from field data and fixed. VBGF growth parameters were estimated from shrimp weight at stocking and biweekly measurements. Mortality rate was estimated from numbers stocked and harvested and was assumed to be constant over time. N or P waste input rates were determined as mass balances by subtracting the N or P incorporated into shrimp tissue from the total feed N or P input. A few environment parameters such as extinction coefficients (k_{Chl} and k_{other}) were taken from the literature (Lorenzen *et al.*, 1997).

Nutrient dynamic parameters were estimated by first solving the ordinary differential equations and then fitting the model to observed time series data for TAN, NO, TP and Chl. Initial ranges for the estimated parameters were obtained from previous studies (Lorenzen *et al.*, 1997; Burford and Lorenzen, 2004). Calibration was carried out within the ranges via a maximum likelihood approach. The goodness of fit was evaluated using the principle of combined least sum of squared differences between observed and predicted values for TAN, NO, TP and Chl. The estimation process was a trial and error effort that sought a set of parameters which had the maximum likelihood and fitted the observed data most accurately. Using optimum estimated parameters, predictions of nutrient components (TAN, NO, TP and Chl) were generated by solving the models for a full production cycle. In order to evaluate model uncertainty, a sensitivity analysis was performed. Sensitivity analysis evaluated the changes in the model outputs with respect to variations of each estimated parameter, which were measured by sensitivity coefficients (Zi *et al.*, 2008).

Once calibrated, the models were used to simulate the impacts of variation in farm management (stocking density and water management) on pond water quality and effluents. End-of-cycle concentrations and loading of TAN, NO, TP, and Chl were generated for a range of stocking densities (75-180 PL m^{-2}) and water exchange rates (1-50% day^{-1}). The combined effects of stocking density and water exchange on nutrient levels and discharge were also evaluated.

Classification of farming types

A total of 14 technical variables were selected. They included: farm area (ha), total number of ponds, average pond size (ha), number of species cultured, shrimp stocking density (PL m^{-2}), number of crops per year, daily water exchange rate (% day^{-1}), aeration time (hours ha^{-1} $crop^{-1}$), feed use (kg ha^{-1} $year^{-1}$), start-up investment (RMB ha^{-1}), variable costs (RMB $year^{-1}$), fixed costs (RMB $year^{-1}$), ratio of family to total labor, and ratio of contracted to total labor.

Following Joffre and Bosma (2009), factor analysis was firstly employed to create a smaller set of composite variables. The new composite variables were orthogonal linear combinations of the original 14 variables. All variables were normalized and the factors were rotated using VARIMAX with Kaiser Normalization to increase interpretability (Michielsens et al., 2002). The extraction method used maximum likelihood. Factor scores were computed to replace the original 14 variables for further use in cluster analysis. Before applying factor analysis to the data set, Kaiser-Meyer-Olkin (KMO) and Bartlett's test were conducted to determine if the data fit model assumptions.

After factor analysis, shrimp farms were clustered according to the new factors. First, both hierarchical (Ward's method) and non-hierarchical (partitioning around medoids, PAM) cluster techniques were adopted to determine optimal number of clusters to ensure quality of results. PAM is a robust variation of well-known K-means method. Graphical results from the two methods were displayed to determine the optimal number of clusters. Then, results from PAM were used to obtain the cluster information. ANOVA and post hoc tests were used to determine if initial variables were significantly different in different clusters, with a significance level alpha at 0.05. Factor and cluster analyses were run using the libraries *stats* and *cluster* in R software environment (version 2.13.1).

Economic performance and influential factors

Economic performance of shrimp farms was compared by identified farming type to determine the most profitable farming system. Survival rate, shrimp yield, costs, profits, and key resource use efficiencies including capital, feed and labor were computed as indicators. ANOVA and post hoc tests were used to recognize significant differences of identified farming systems with a significance level alpha at 0.05.

Multiple regression analysis was used to predict yield (tons ha^{-1} yr^{-1}) and profits (RMB ha^{-1} yr^{-1}) as functions of management variables using the backward selection method. Management variables included farm size (ha), stocking density (PL m^{-2}), daily water exchange rate, aeration rate (hrs ha^{-1} yr^{-1}), feeding rate (tons ha^{-1} yr^{-1}). Independent variables were entered at probability ≤ 0.10.

Disease risk

Three disease scenarios including worst, best, and most probable case were modeled to help define the risk range for each farming system. Mortality rate due to disease outbreak in each case was used as the indicator. Farm owners or head managers were asked to provide or estimate mortality rate for each scenario based on farm records or disease outbreak history in the past five years. In this analysis, mortality rate represented the percent mortality of shrimp caused by disease outbreak in each farm. Shrimp yield was estimated based on the mortality rate for each scenario and compared with the base yield. The base yield was assumed as yield derived from the main survey.

Social analysis

For social analysis, another survey was conducted to investigate changes in quality of life of shrimp farmers and other farmers in the villages. Perceptions from 100 shrimp farmers and 100 other villagers were randomly collected. The questionnaire for the survey examined individual perceptions of health and wellbeing, community, crime and safety, education and work, and the environment. Data was analyzed using chi-square test with a significance level at 0.05.

RESULTS

Nutrient dynamic modeling

Most management and environment parameters were determined from field data and fixed (Table 1). Parameters to be estimated included s, n, v, g_{max}, I_{ratio}, k_{SN}, k_{SP}, c, u, b_P. The N and P dynamic models were optimized to extract a combination of 10 nutrient dynamics parameters that provided best fit to the observed data of TAN, NO, TP and Chl.

The calibrated models were run for the whole production cycle and simulated values were plotted against the observed values (Figure 1). The models provided fairly good approximations to the observed TAN, NO, TP and Chl concentrations with predicted values varying randomly from observed values (R^2=0.94). No significant differences were found between predicted and observed values of TAN, NO, TP and Chl ($P > 0.1$). TAN concentrations increased nearly exponentially and reached 1.9 mg l^{-1} by the end of production. Compared to TAN, NO increased mildly over the production cycle and reached maximum about 1 mg l^{-1} at the end. TP concentrations increased continuously during the first two months, declined slightly from day 60 to 70, and increased again subsequently. Chl concentrations increased gradually in the first month and reached an approximate plateau at 0. 32 mg l^{-1} during the final month of grow-out, but declined slightly at the end.
The combined effects of stocking density and water management on end-of-cycle concentrations of TAN, NO, TP, and Chl were simulated (Figure 2). Increasing stocking density and reduced water exchange rate increased the end-of-cycle concentrations of TAN, NO, and TP. NO and TP levels were dominated by water management when exchange rates were 20% day^{-1} or above. Chl concentrations were mainly determined by water exchange. Chl concentrations decreased with increasing water exchange, regardless of the stocking density. Lowest concentration of Chl was achieved at highest water exchange rate.
The combined effects of stocking density and water management on nutrient loading from one shrimp pond (pond size = 0.3 ha) were also simulated (Figure 3). At lower water exchange rate up to 20% per day, loading of NO was less than 10 kg from the pond (< 30 kg ha^{-1}). NO discharge reached maximum at the highest stocking density and 30% daily water exchange, and declined with higher water change rates. TAN discharge was less than 40 kg from the pond (< 120 kg ha^{-1}) with water exchange rate less than 20%, regardless of stocking density. With 20% of water exchange and above, loading of TAN increased with increasing stocking density and water exchange. Loading of TP showed a similar overall trend as that of TAN. Loading of Chl was mainly determined by water exchange, with an increasing trend for water exchange rates from 1-15% and then declining afterwards.

Classification and characterization

Data collected in this study were appropriate for a factor analysis, with KMO (Kaiser-Meyer-Olkin) of 0.838 (> 0.7 is relatively high) and Bartlett's test that was significant ($P < 0.05$). Factor analysis identified three orthogonal linear combinations of the 14 original, partially correlated variables. The three-factor solution cumulatively explained 86.1% of the total variance in the data, which was excellent (Table 2). Most uniqueness values were smaller than 0.5 and close to 0, which suggested the model fit well. We started by retaining and highlighting variables with loadings larger than 0.5 in absolute value to be the main components of each factor.

Factor 1 had nine main components, eight with positive signs (shrimp stocking density, number of crops, water exchange rate, aeration rate, feeding rate, start-up investment cost, variable and fixed costs) and one with a negative sign (average pond size). Factor 1 contrasted average pond size with the other main components. This factor therefore represented the intensification degree of shrimp farming, showing that intensive shrimp farms with positive scores on this factor usually operated smaller ponds with higher stocking density, more crops per year, higher water exchange and aeration rates, as well as higher level of start-up investment and operating inputs. Shrimp farms with positive scores on this factor represented intensive farms. Factor 1 accounted for 47.7% of the total variance.

Factor 2 was composed of two groups with four main components. The first group with positive signs included farm area, total number of ponds, and ratio of contracted to total labor. The second group with a negative sign consisted of ratio of family to total labor. Factor 2 indicated both farm scale and labor origin, and contrasted family based small- or medium-scale farms with commercial based large-scale farms. This factor accounted for 24.1% of the total variance in the set of 14 original variables.

Factor 3 had two main components and contrasted the number of species cultured with shrimp stocking density. It explained that stocking density was low in polyculture and high in monoculture farms. Factor 3 could be described as farm diversity. This factor explained 14.1% of total variance of the data.

Cluster analysis based on these three factors was used to identify principal farming types. Dendrogram, cluster, and silhouette plots reached an agreement showing the presence of four clusters (Figure 4, 5 and 6). The silhouette plot showed the silhouettes of all four clusters next to each other. The silhouette value summarized how appropriate each object's cluster was to the overall plot. The quality of clusters can be compared based on silhouette width (S_i, ranging from 0.25 to 0.5 indicate weak structure; 0.5-0.75 reasonable structure; and 0.75-1 strong structure). Silhouette width values of cluster 1, 3 and 4 were all larger than 0.75 which indicated a strong structure in each cluster. Cluster 2 had a relatively weak structure since the silhouette value was only 0.33. But the overall average silhouette width of the silhouette plot was 0.69 which indicated a reasonable overall structure was detected.

The four clusters represented four distinctively different types of shrimp farms. All farming types grouped by clustering analysis were characterized in terms of the 14 original technical variables in Table 3. Cluster 1 was intensive shrimp farms operated by families (intensive family); cluster 2 was intensive shrimp farms operated by commercial companies (intensive commercial); cluster 3 was semi-intensive shrimp farms, and cluster 4 polyculture farms.

Intensive family and commercial farms shared many similar characteristics. They both operated significantly smaller ponds with significantly higher stocking densities compared to semi-intensive and polyculture farms ($P < 0.05$). Both intensive farming systems produced shrimp year-round with a total of three crops and duration of 90-120 days per crop. They had significantly higher water exchange rates and aeration as well as higher feed use compared to the other two farming types ($P < 0.05$). The start-up investment and annual operating costs including fixed and variable costs were also significantly higher in the two intensive farming types than in semi-intensive and polyculture ($P < 0.05$). Intensive family had the highest start-up cost per hectare and annual fixed costs of all farming types ($P < 0.05$). In general, intensive family farms were relatively similar to intensive commercial farms in terms of intensification and farm diversity. They mainly differed in labor origin and farm size. Intensive family farms were small (< 3.3 ha) or medium (3.3-6.7 ha) scale with household members working in the farms. Intensive commercial farms had larger farm areas (> 6.7 ha) with only hired labor.

Semi-intensive and polyculture farms often operated ponds at least two-fold larger than those of intensive farming types. They were usually family based at small or medium scales. Semi-intensive farming used monoculture with lower stocking density and less intensification compared to intensive systems. Polyculture farms integrated shrimp culture with other fish, mainly tilapia. Polyculture farms had shrimp stocked at the lowest density, with only 38 post-larvae per m^2. Semi-intensive farms usually had two crops per year with duration of 120-150 days for each crop. Polyculture farms had two to three crops each year depending on the targeted harvest size of shrimp. Due to lower stocking density, water exchange and aeration rates were significantly lower for semi-intensive and polyculture farms than intensive farms ($P < 0.05$). Semi-intensive and polyculture farms used commercial feed and also relied on natural food produced in the pond. Thus they had significantly lower feed use per ha than intensive farming ($P < 0.05$). They also had lower start-up costs and annual operating costs than intensive farms.

Break down of operating costs by identified farming systems showed that feed was the major variable input cost in all farming systems (Table 4). Seed and electricity were the other high input costs in both intensive farming systems. Fertilizers and seed were also main input costs in the semi-intensive farming system. Of fixed costs, land lease was the major input cost in all farming systems.

Economic performance

Shrimp yields, production costs, profits, survival rates, and resource (feed, capital, and labor) use efficiency were computed for the four shrimp farming systems (Table 5). Semi-intensive farms had the highest shrimp survival rates at around 77%. Survival rates in the other farming systems were only 62%-65%. Intensive family and commercial farms had significantly higher shrimp yields than semi-intensive farms ($P < 0.05$) and the lowest shrimp yield was obtained in polyculture farms. Production costs per kilogram of shrimp were highest in intensive family and commercial farms (around US$ 2.7 based on current exchange rate), followed by semi-intensive (around US$ 2.1) and polyculture (around US$ 1.05) farms. Intensive family and commercial farms had similar profits, the highest of all systems (around US$ 9,500 ha^{-1} $crop^{-1}$), while semi-intensive farms obtained about half of that profit. By obtaining extra profit from other cultured species, polyculture farms obtained significantly higher profits than semi-intensive farms, but were still lower than intensive farms ($P < 0.05$).

Differences in resource use efficiency were also observed. The average feed conversion ratio (FCR) was similar for intensive family and commercial farms, which were significantly higher than semi-intensive and polyculture farms ($P < 0.05$). Semi-intensive and polyculture farms showed significantly higher capital use efficiency than intensive farms ($P < 0.05$). Labor productivity of intensive family and commercial farms was significantly higher than semi-intensive family farms. By integrating fish production, polyculture farms had the highest labor productivity. If fish production was excluded, labor productivity in polyculture farms would be the lowest.

Influential factors for yields and profits

Both models were similar with more than 90% of variability in the data explained by the same three predictor variables (Table 6 and 7). These predictor variables included stocking density, feeding rate and aeration rate, which had significant effects on yields and net profits and were considered influential factors. Two other independent variables, farm size and water exchange rate, showed insignificant impacts on the two response variables and thus were excluded from the models. All three influential factors were positively correlated with yields and net profits.

Disease risk

According to farm records and farmer's estimation, if disease occurred, an average of 78.4% of shrimp would die in the worst case, 35.6% in the most probable case, and 12.2% in the best case for all shrimp farms. Shrimp yields from the three scenarios including worst, best, and most probable case were estimated for each farming type and compared with base yields from disease free farms

(Figure 7). Disease outbreak showed highest influence on intensive farming, especially on intensive family farms. Polyculture farms were least affected by disease occurrence.

Perceptions of changes in quality of life

All respondents agreed that shrimp farming had significant positive impacts on the development of their community in general during the last 10 years ($P < 0.05$). The positive impacts included: 1) higher standard of living, including more job opportunity and higher salary; 2) the environment of the village was generally better than in the past, for example, more roads were built; 3) more educational opportunity for children; 4) less crime in the village; 5) less illness than in the past, and people who got sick had more access to medical service; and 6) villages had grown in the last 10 years. However, farmers also agreed that more water and soil pollution were caused by shrimp farming in the region.

DISCUSSION

The dynamic models developed provided satisfactory fits ($R^2 = 0.94$) to the time series concentrations of TAN, NO, TP and Chl for the Chinese commercial shrimp farm. Most estimated parameters were comparable with the ranges provided by a pioneer study (Lorenzen et al., 1997). Predicted concentrations of nutrient components were also consistent with corresponding values in previous studies on shrimp farming (Lorenzen et al., 1997; Funge-Smith and Briggs, 1998; Jackson et al., 2003; Burford and Lorenzen, 2004). There were several comprehensive models on N and P dynamics in aquacultural systems (Lorenzen et al., 1997; Montoya et al., 2000; Jimenez-Montealegre et al., 2002; Burford and Lorenzen, 2004). Those studies were focused on systems under different environmental conditions and management scenarios, and therefore could not be directly compared to our results. This study could serve as a basis for integrating management parameters such as farm intensity and water exchange to simulate nutrient discharge by fish ponds in relation to time. Results of the models could be utilized for examining potential environmental impacts of shrimp farming and advising the regulation for more sustainable development of the sector.

Several studies on nutrient mass balances in shrimp ponds indicated that the major source of nutrient input was shrimp feed (Funge-Smith and Briggs, 1998; Jackson et al., 2003; Casillas-Hernández et al., 2006). N and P loads to the environment depended to the quantity and quality of feed input (Castello et al., 2008). In general, about 75% of the feed N and P were unutilized and entered the water column as waste (Crab et al., 2007). In this study, only 32% of N and 15% of P inputs from feed were incorporated into shrimp biomass. The estimated environmental losses of N and P per ton of shrimp produced for the model shrimp system were 72 and 18 kg/ton, respectively. Nutrient losses were about 701 kg N ha^{-1} $cycle^{-1}$ and 176 kg P ha^{-1} $cycle^{-1}$ from Chinese intensive shrimp ponds. Of these losses, 120 kg N ha^{-1} $cycle^{-1}$ in dissolved form (TAN+NO) and 62 kg P ha^{-1} $cycle^{-1}$ were discharged through regular daily water exchange. Other major sinks of N and P would be sediment and harvest drainage. Our results were comparable with previous studies, which indicated about 18%-22% of the input N and 6%-14% of input P were assimilated by shrimp (Funge-Smith and Briggs, 1998; Jackson et al., 2003; Xia et al., 2004). Estimated nutrient losses from intensive shrimp ponds were about 860 kg N ha^{-1} $cycle^{-1}$ and 184 kg P ha^{-1} $cycle^{-1}$ (Briggs and Funge-Smith, 1994). The estimated environmental losses of N and P per ton of shrimp produced in semi-intensive shrimp ponds were 73.3 and 13.2 kg/ton, respectively (Casillas-Hernández et al., 2006). Our results of nutrient losses per ton of shrimp produced were comparable with those of semi-intensive systems due to high unit production in the intensive ponds.

The relationship of stocking density, water management and nutrient concentrations is complex and poorly understood (Lorenzen et al., 1997). Water exchange and stocking density can influence most water quality parameters, including ammonia, nitrite, nitrate, Kjeldahl nitrogen, soluble orthophosphate and phytoplankton (Hopkins et al., 1993). Our simulation results consistently showed that both stocking density and water exchange had important effects on TAN, NO and TP levels. At high stocking densities, high rates of water exchange were required to substantially reduce nutrient levels in ponds. Since the maximum phytoplankton assimilation capacity was already achieved, concentration of Chl was mainly affected by water exchange. Both stocking density and water exchange could influence nutrient loading. According to our results, low stocking density and reduced water exchange could decrease nutrient loading to receiving waters.

System optimization through better management is essential for future shrimp farming to be more sustainable. System optimization requires minimizing nutrient loading and maximizing shrimp production. This puts us in a dilemma. Minimizing nutrient loading needs us to reduce water exchange and use lower stocking density. But increasing stocking density is a key approach to maximize shrimp production, and increasing water exchange is needed to achieve a higher survival rate for ponds with high stocking density. To solve the dilemma, voluntary adoptions of best management practices (BMPs) or good aquaculture practices (GAPs) have been promoted recently as a reasonable and affordable means to maintain relatively high production and meanwhile minimize environmental impacts from pond effluents (Stanley, 2000; Boyd, 2003). Nutrient loads in pond effluents may be minimized through applications of some BMPs and GAPs including moderate stocking density within the assimilation capacity of ponds and reduced water exchange rate (Boyd, 2003). Lower stocking density reduces total N and P inputs and lower water exchange rate reduces effluent quantities. The estimated environmental losses of N and P per ton of shrimp produced for the model shrimp system were 72 and 18 kg/ton, respectively. Other BMPs and GAPs such as sludge removal, optimum feeding regimes and sufficient mechanical aeration are also critical in controlling nutrient dynamics in the pond and reducing loading to the receiving waters.

Shrimp farming in China is highly diversified and concentrated, but geographically divided. Most production occurs in southern China, mainly Guangdong, Fujian, Hainan, and Zhejiang provinces. Shrimp farms anually culture two to three crops per year in southern China, while only one to two crops in northern China (Biao and Kaijin, 2007). The majority of extensive shrimp farms have been replaced by more intensified farming types. For our analysis, a total of 100 shrimp farms across the concentrated shrimp farming region in Hainan province were included. Total area of our sampled farms was 715 hectares, representing 8.5% of shrimp farming area in this province in 2010. Joffre and Bosma (2009) failed to include larger intensive commercial farms due to limited access to these farms because of contamination and disease issues. Under the assistance of local technicians, we were able to visit a few large commercial farms wearing special uniforms after strict sterilization procedures, and successfully incorporated them into our study.

Aquaculture typologies are often determined by levels of farm intensity, using indicators such as stocking density and level of inputs (Joffre and Bosma, 2009). Following Joffre and Bosma (2009), we employed similar variables that reflected operating characteristics, diversity, and labor origin of shrimp farms. We also added new technical variables such as water exchange rate and aeration rate. Rather than using a traditional conceptual classification by intensity in uni-dimensional manner (usually just stocking density), we employed multivariate analysis to develop an empirical-based multi-dimensional typology, which better captured the true complexity of shrimp farming sector (Michielsens et al., 2002). The analysis helped us identify four types of shrimp farming systems distinguished by intensity, origin of labor and species diversity: intensive family and commercial, semi-intensive and polyculture of shrimp with tilapia. Our classification results were consistent with information of farm type provided by shrimp farmers.

Farm profitability is always influenced by management practices and fluctuation of market price (Paul and Vogl, 2011). Poor management can lead to reduced production and lower profitability even when prices rise (Smith et al., 2010). Though operated at highest costs with highest feed use, the two intensive farming systems were still the most profitable types and performed well in terms of capital and labor use. This was due to high shrimp yields and better market prices. Intensive farms tended to grow larger shrimp by using specific pathogen free (SPF) post-larvae, and sold them at a higher farm-gate price. Joffre and Bosma (2009) stated that intensive farming systems were generally economically sustainable in a short term but not on the long term. Future research is needed to improve intensive systems to achieve long-term economic sustainability. Our study found survival rates were higher in semi-intensive ponds than intensive ponds due to lower stocking density and better water quality in the former ponds. High survival rates of shrimp could also be achieved in small intensive ponds under better management practices (Ruiz-Velazco et al., 2010).

Polyculture outperformed semi-intensive and ranked as the third most profitable farming system. Most polyculture farms were actually converted from semi-intensive farms to gain extra profits that would compensate for risk of disease outbreak. By integrating shrimp farming with fish and maintaining shrimp at a lower density, polyculture farms had more secure production and their financial risk was reduced. However, polyculture did not prevent farms from virus infections and farms were still vulnerable to disease if inappropriately managed. In our study, polyculture farms integrated shrimp and tilapia with ratios of 10:1 (30 PL per m^2 and 3 fish per m^2 for fish with size of 10 g) or 15:1 (45 PL per m^2 and 3 fish per m^2 for fish with size of 10 g) in earthern ponds. Those ratios were considered as optimum and recommended by local researchers.

Stocking density, feeding and aeration rate were the key management techniques which could significantly influence farm profitability in Chinese shrimp farming systems. Though stocking density was positively correlated to profitability, it should not exceed a pond's carrying capacity. Schwantes et al. (2009) found feeding rate and water exchange had the greatest impacts on prawn production in Thailand. They also included indirect predictors that were descriptive of the management strategy such as stocking PLs directly or nursing them in separate ponds, and found a farmer's years of experience and harvest methods also had significant impacts on net profits. We found farm size and water exchange rate had insignificant effects on farm profits. Pond size was also shown to be important in explaining profitability of shrimp farms by Gordon and Bjørndal (2009). Small production units may also lead to better management (Milstein et al., 2005). Ruiz-Velazco et al. (2010) also found that aeration was an important factor determining survival rates and final production for shrimp ponds in intensive commercial farms. High aeration rates or earlier start of aeration resulted in higher survival rates. In that study, raising aeration from 9000 to 14000 horsepower per hour per hectare increased production by 32%. Starting aeration after 5 weeks resulted in an 18% decrease in shrimp yield compared to starting at the beginning of the culture cycle (Ruiz-Velazco et al., 2010).

Shrimp farmers were also asked to rank the major problems that might significantly affect farm profitability during our survey. The top five problems were: disease outbreak, low farm-gate price, poor seed quality, high feed price and poor water quality. Disease outbreak was identified as the most important problem and was attributed to external pollution, poor water and seed quality by farmers. Thai prawn farmers also cited external pollution, seed qualty, pond water quality and poor soil quality as the main causes of disease prevalence (Schwantes et al., 2009). External pollution was mainly caused by agricultural and aquacultural activities. Specific pathogen free (SPF) strains of white shrimp were introduced from North America to solve the issue of poor seed quality, as they were more disease resistant and grew faster than local strains. A shift from black shrimp to SPF white shrimp enabled Thailand to reduce the risk of disease outbreak in the shrimp industry (Bhattacharya and Ninan, 2011). However, new diseases emerged and disease problems still disturbed this sector (Bhattacharya and Ninan, 2011). Our results indicated that disease outbreak could cause only 12% to 36% crop failure in the best or most probable cases, and as much as 78% crop failure in the worst cases. Disease risk usually depends on the causes of disease, such as bacteria or virus based, time of disease occurrence, shrimp size at that time, and management stategies. Most shrimp farmers harvest once disease is detected while shrimp are still marketable. The risk of disease also rose with increased intensity and stocking densities, and when polyculture was replaced by monoculture (Kautsky et al., 2000). Approximately 26% of farms in our survey reported experiencing partial crop failure caused by disease outbreak in the past. Most of these were intensive family-based farms. Disease outbreak had larger impacts on intensive farming, particularly intensive family farms, than on semi-intensive and polyculture. This was probably because high stocking density facilitated the spread of pathogens. Under the worst case scenario in our model, massive crop failure would produce zero to negative returns for both types of intensive farms, while most polyculture farms could still gain positive profits. Joffre and Bosma (2009) found that intensive commercial farms had significantly lower percentages of disease outbreak compared to intensive family and polyculture farms in Vietnam. They indicated that higher technological investments in water treatment and water quality monitoring could reduce the risk of disease outbreak. However, they were unable to survey many larger intensive commercial farms in their study. They also recommended minimizing water exchange to prevent contamination by external pollution. Aeration management in intensive ponds was also recommended as an approach to reduce mortality from disease (Ruiz-Velazco et al., 2010).

The majority of farms (86%) in our survey discharged untreated effluents directly into receiving waters. Only a few intensive commercial farms treated pond effluents using chemical or biological techniques before discharge. However, all interviewed farmers were aware of the potential problems caused by discharge of untreated pond effluents. More than half of farms (58%) in our survey were reluctant to invest money on effluent treatment and would only be willing to implement effluent treatment under mandatory requirement by the government.

Given the high tradability of shrimp, trade policy can be another mechanism to promote more sustainable production. Leading shrimp importers, including the United States, Japan, and the European Union, have imposed more stringent trade policies to ensure quality of imported shrimp. There is a growing demand for eco-labeled or certified shrimp products from these developed countries. Third-party certification and eco-labeling are private initiatives which can differentiate shrimp products from well managed or poorly managed farms (Smith et al., 2010). Leading importers are willing to pay a premium for shrimp with eco-labels or shrimp produced by certified farms that adopt good aquaculture practices (GAP) or best management practices (BMP). One of the main problems with establishing certification guidelines around the world is due to lack of comprehensive information about the local environmental impacts of aquaculture (WWF, 2008). GAP and BMP standards for shrimp farm certification were initially designed for large-scale commercial farms (Boyd, 2011). Certification programs have not been widely established in China since the majority of shrimp farms are small-scale, family operated. Even for commercial large-scale farms, only a few are certified. Certification programs are currently evaluating ways to integrate and group small-scale farms for inspection and certification by the use of farm clusters or cooperatives (Boyd, 2011). Many respondants in our survey (42%), mostly from intensive farms, showed interest in participating in certification programs for a better market price of shrimp. The rest (58%) expressed no interest at all and thought it was waste of money to be certified. An interesting shift of commodity chain from simple buyer-driven to twin-driven mode has been observed in Bangladesh. In the twin-driven commodity chain, buyers govern the supply network and third-party certifiers control the regulatory aspects of the industry (Islam, 2008). This new commodity chain offers great opportunities for sustainable shrimp farming by adopting GAP or BMP and participating in certification programs. It could be a model for the Chinese shrimp farming industry to promote more sustainable production.

ACKNOWLEDGMENTS

We would like to thank shrimp farmers and technicians from local feed companies for their generous cooperation and Prof. Lai, Qiuming from Hainan University for his assistance in data collection.

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Table 1. Model parameters.

Model parameters	Values	Reference
Management/environment parameters (fixed)		
K (shrimp VGBF growth rate, % day^{-1})	0.84	
W_{∞} (shrimp VGBF maximum weight, g)	72	
W_0 (shrimp VGBF stocking weight, g)	0.08	
N_0 (stocking density, PL l^{-1})	0.09	
M (mortality rate, % day^{-1})	0.5	
z (water depth, m)	1.5	
a_N (N input rate, mg N g^{-1} shrimp day^{-1})	1.1	
a_P (P input rate, mg P g^{-1} shrimp day^{-1})	0.25	
q (proportion of N entering as TAN)	0.9	Burford and Lorenzen, 2004
b_N (allometric scaling of TAN input)	0.75	Lorenzen et al. (1997)
k_{other} (extinction coefficient non-Chl)	4	Lorenzen et al. (1997)
k_{chl} (extinction coefficient Chl)	11.9	Lorenzen et al. (1997)
f (water exchange rate, % day^{-1})		
Month 1	1	
Month 2	5	
Month 3 onwards	10	
Nutrient dynamics parameters (estimated)		
s (sinking rate of dead algae, % day^{-1})	6.4	
n (nitrification rate, % day^{-1})	9.9	
v (volatilization rate, % day^{-1})	4.8	
g_{max} (maximum algae daily growth rate, day^{-1})	0.59	
I_{ratio} (ratio surface/saturation light intensity)	0.83	
k_{SN} (N half-saturation, mg l^{-1})	0.0043	
k_{SP} (P half-saturation, mg l^{-1})	0.0036	
c (nitrogen-to-chl ratio)	4.8	
u (phosphorus-to-Chl ratio)	2.1	
b_P (allometric scaling of TP input)	0.69	

Table 2. The rotated factor matrix, result from a maximum likelihood analysis based on 14 variables from 100 shrimp farms.

Parameters	Factor 1	Factor 2	Factor 3	Uniqueness
Farm area (ha)	.098	.966	.219	0.01
Total number of ponds	.226	.916	.288	0.028
Average pond size (ha)	-.761	-.199	-.193	0.344
Number of species cultured	-.351	.068	-.929	0.009
Shrimp stocking density (PL m^{-2}) *	.709	.114	.646	0.068
Number of crops	.857	.281	.175	0.156
Water exchange rate (%)	.729	.237	.403	0.25
Aeration rate (hours ha^{-1} $year^{-1}$)	.873	.306	.269	0.071
Feeding rate (tons ha^{-1} yr^{-1})	.887	.406	-.195	0.011
Start-up investment cost (RMB ha^{-1}) #	.908	.176	.305	0.05
Variable costs (RMB $year^{-1}$)	.919	.369	.127	0
Fixed costs (RMB $year^{-1}$)	.905	-.037	.197	0.15
Ratio family/total labor	-.252	-.694	.151	0.432
Ratio contracted/total labor	.229	.721	-.226	0.377
% of the total variation explained by the factor	47.7	24.3	14.1	

Note: *PL= post larvae; #1 RMB = 0.15 USD.

Table 3. Technical characteristics of Chinese shrimp farming systems identified by cluster analysis.

	Cluster: Intensive family	Intensive commercial	Semi-intensive	Polyculture
Numbers	25	25	25	25
Farm area (ha)	3.14 ± 1.72^{b}	17.8 ± 8.35^{a}	2.84 ± 1.5^{b}	4.9 ± 3.35^{b}
Total number of ponds	9 ± 6^{b}	51 ± 24^{a}	3 ± 2^{b}	6 ± 4^{b}
Average pond size (ha)	0.309 ± 0.05^{b}	0.311 ± 0.04^{b}	0.759 ± 0.23^{a}	0.725 ± 0.22^{a}
Number of species cultured	1 ± 0.0^{b}	1 ± 0.0^{b}	1 ± 0.0^{b}	2 ± 0.0^{a}
Shrimp stocking density (PL m^{-2})	144 ± 19^{a}	140 ± 14^{a}	92 ± 9^{b}	38 ± 8^{c}
Number of crops	3 ± 0.0^{a}	3 ± 0.0^{a}	2 ± 0.0^{c}	2.16 ± 0.374^{b}
Water exchange rate (% day^{-1})	17.2 ± 5.79^{a}	17 ± 4.79^{a}	6.44 ± 2.45^{b}	3.12 ± 1.27^{c}
Aeration rate (hrs ha^{-1} $year^{-1}$)	$54{,}700 \pm 108{,}00^{a}$	$60{,}000 \pm 9{,}640^{a}$	$6{,}190 \pm 1{,}670^{b}$	$7{,}920 \pm 2{,}200^{b}$
Feeding rate (ton ha^{-1} $year^{-1}$)	50.9 ± 4.7^{a}	50.6 ± 5.29^{a}	14.1 ± 1.83^{c}	34.8 ± 4.34^{b}
Start-up costs (RMB ha^{-1})	$528{,}000 \pm 31{,}400^{a}$	$476{,}000 \pm 13{,}200^{b}$	$174{,}000 \pm 22{,}200^{c}$	$163{,}000 \pm 13{,}700^{c}$
Variable costs (RMB ha^{-1} $year^{-1}$)	$552{,}000 \pm 45{,}500^{a}$	$567{,}000 \pm 51{,}600^{a}$	$158{,}000 \pm 14{,}500^{c}$	$24{,}9000 \pm 27{,}000^{b}$
Fixed costs (RMB ha^{-1} $year^{-1}$)	$96{,}800 \pm 15{,}800^{a}$	$70{,}200 \pm 8{,}790^{b}$	$32{,}100 \pm 4{,}880^{c}$	$33{,}300 \pm 4{,}670^{c}$
Ratio family/total labor	0.42 ± 0.2^{b}	0^{d}	0.6 ± 0.27^{a}	0.27 ± 0.19^{c}
Ratio contracted/total labor	0.49 ± 0.2^{c}	0.89 ± 0.1^{a}	0.31 ± 0.25^{d}	0.68 ± 0.17^{b}

Note: cluster values were presented as mean ± standard deviation. Values in the same row with different superscript letter were significantly different ($P < 0.05$).

Table 4. Break down of operating costs by farming system.

	Intensive family	Intensive commercial	Semi-intensive	Polyculture
Feed	61%	63%	51%	74%
Fertilizers	0%	0%	9%	1%
Seed	10%	8%	8%	3%
Chemicals	4%	6%	4%	1%
Electricity	8%	8%	7%	4%
Labor	2%	3%	3%	4%
Other	1%	1%	2%	1%
Total variable costs	**86%**	**89%**	**83%**	**88%**
Land lease	8%	6%	9%	7%
Depreciation	6%	3%	6%	4%
Maintenance	0%	1%	1%	1%
Total fixed costs	**14%**	**11%**	**17%**	**12%**

Table 5. Comparison of economic performance and resource use efficiency of shrimp farming systems (mean ± S.D.).

Parameters	Cluster			
	Intensive family	Intensive commercial	Semi-intensive	Polyculture
Survival rate (%)	62.6 ± 8.2^{b}	62.4 ± 7.5^{b}	77.2 ± 3.8^{a}	65.6 ± 7.4^{b}
Shrimp yield (ton ha^{-1} $crop^{-1}$)	12.6 ± 0.79^{a}	12.4 ± 0.97^{a}	6.98 ± 0.47^{b}	3.12 ± 0.58^{c}
Shrimp yield (ton ha^{-1} $year^{-1}$)	37.9 ± 2.4^{a}	37.1 ± 2.9^{a}	14 ± 0.93^{b}	6.63 ± 1.1^{c}
Cost per kg of shrimp (RMB kg^{-1})	17.2 ± 0.67^{a}	17.3 ± 0.96^{a}	13.6 ± 0.58^{b}	6.8 ± 0.34^{c}
Profit (RMB ha^{-1} $year^{-1}$)	$191{,}000 \pm 1{,}9000^{a}$	$183{,}000 \pm 17{,}000^{a}$	$72{,}600 \pm 6{,}300^{c}$	$99{,}700 \pm 7{,}400^{b,*}$
Profit (RMB ha^{-1} $crop^{-1}$)	$63{,}600 \pm 6{,}500^{a}$	$61{,}000 \pm 5{,}600^{a}$	$36{,}300 \pm 3{,}100^{c}$	$47{,}300 \pm 7{,}500^{b,*}$
Feed conversion ratio (FCR)	1.34 ± 0.07^{a}	1.36 ± 0.07^{a}	1 ± 0.09^{b}	1 ± 0.08^{b}
Capital use efficiency	1.29 ± 0.03^{b}	1.28 ± 0.02^{b}	1.38 ± 0.04^{a}	1.36 ± 0.05^{a}
Labor productivity (kg day^{-1})	72.8 ± 24.9^{b}	83.8 ± 27.2^{b}	56.8 ± 23.6^{c}	$120.8 \pm 30.7^{a,*}$

Note: cluster values were presented as mean ± standard deviation. Values in the same row with different superscript letter were significantly different ($P < 0.05$). *Fish production in the polyculture was included to calculate profits and labor productivity.

Table 6. Influential factors of net profits and their coefficients based on multiple linear regression modeling (constant = 31,900;adjusted R2 = 0.932).

Predictors	Unstandardized coefficient ± Std. Error	Standardized coefficient	*P*-value
Aeration rate (hrs ha^{-1} yr^{-1})	0.878 ± 0.152	0.435	<0.05
Feeding rate (ton ha^{-1} yr^{-1})	1,600 ± 178	0.473	<0.05
Stocking density (PL m^{-2})	154 ±58.4	0.13	<0.05
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Table 7. Influential factors of yields and their coefficients based on multiple linear regression modeling (constant = -7.17; adjusted R^2 = 0.975).

Predictors	**Unstandardized coefficient ± Std. Error**	**Standardized coefficient**	***P*-value**
Aeration rate (hrs ha^{-1} yr^{-1})	.0001 ± 0	.267	<0.05
Feeding rate (ton ha^{-1} yr^{-1})	.175 ± 0.028	.197	<0.05
Stocking density (PL m^{-2})	.192 ± 0.009	.615	<0.05

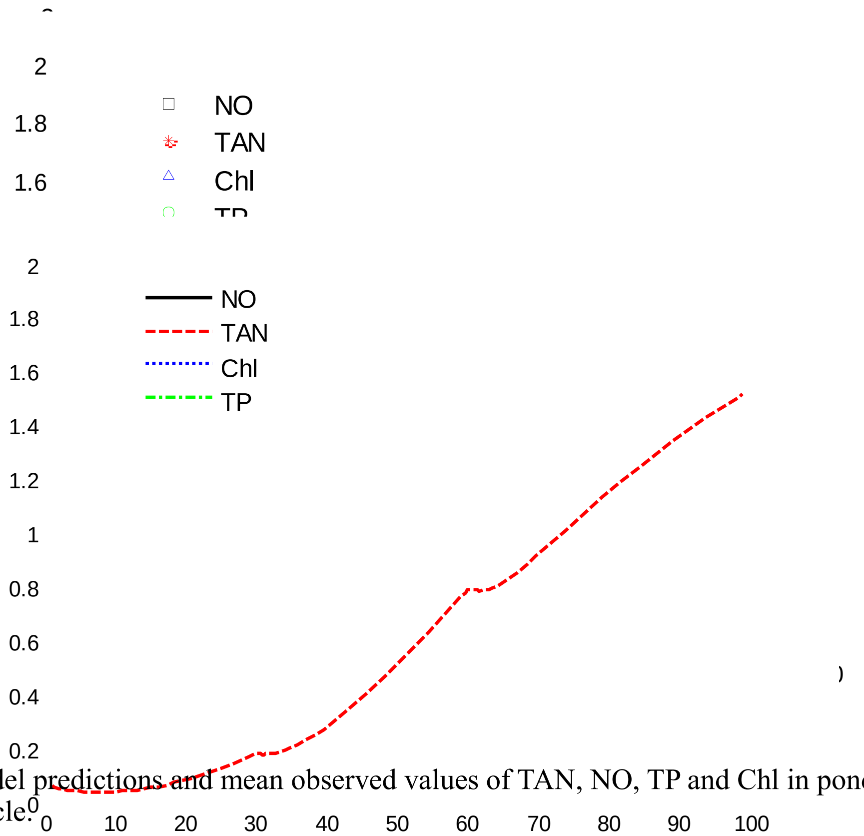

Figure 1. Model predictions and mean observed values of TAN, NO, TP and Chl in pond water over a production cycle.

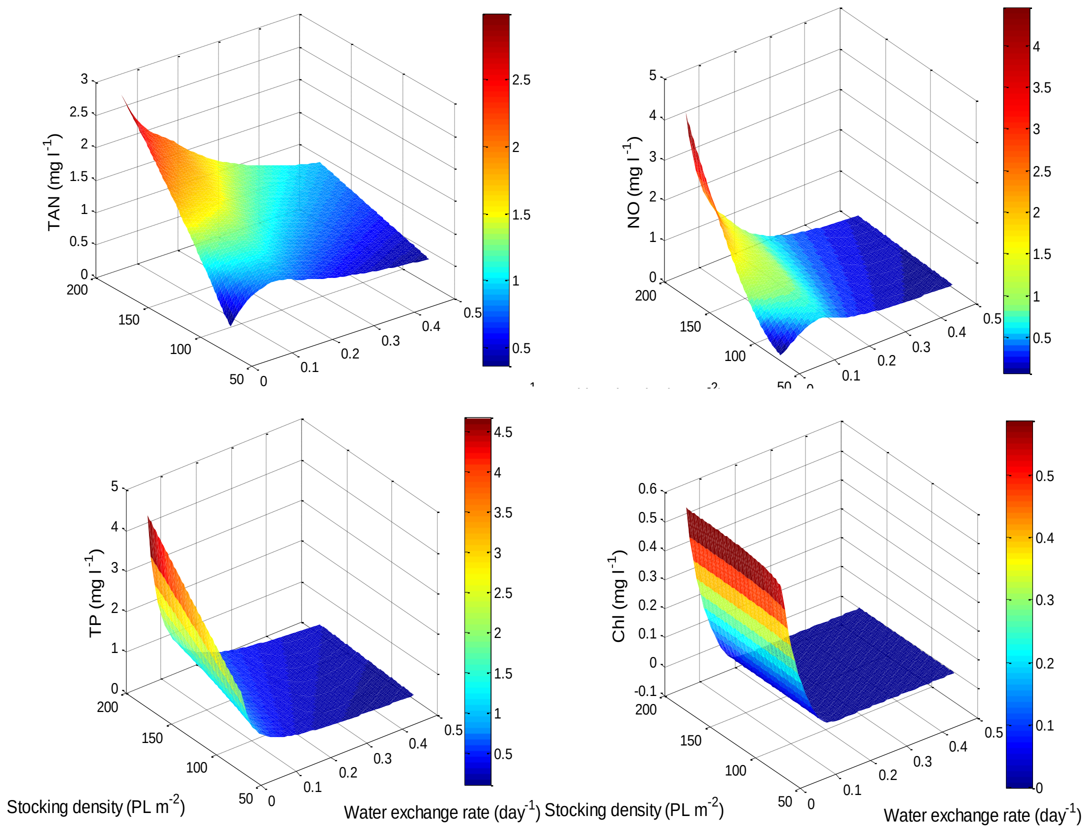

Figure 2. The combined effects of stocking density and water exchange on concentrations of TAN, NO, TP and Chl in pond water at the end of the production cycle.

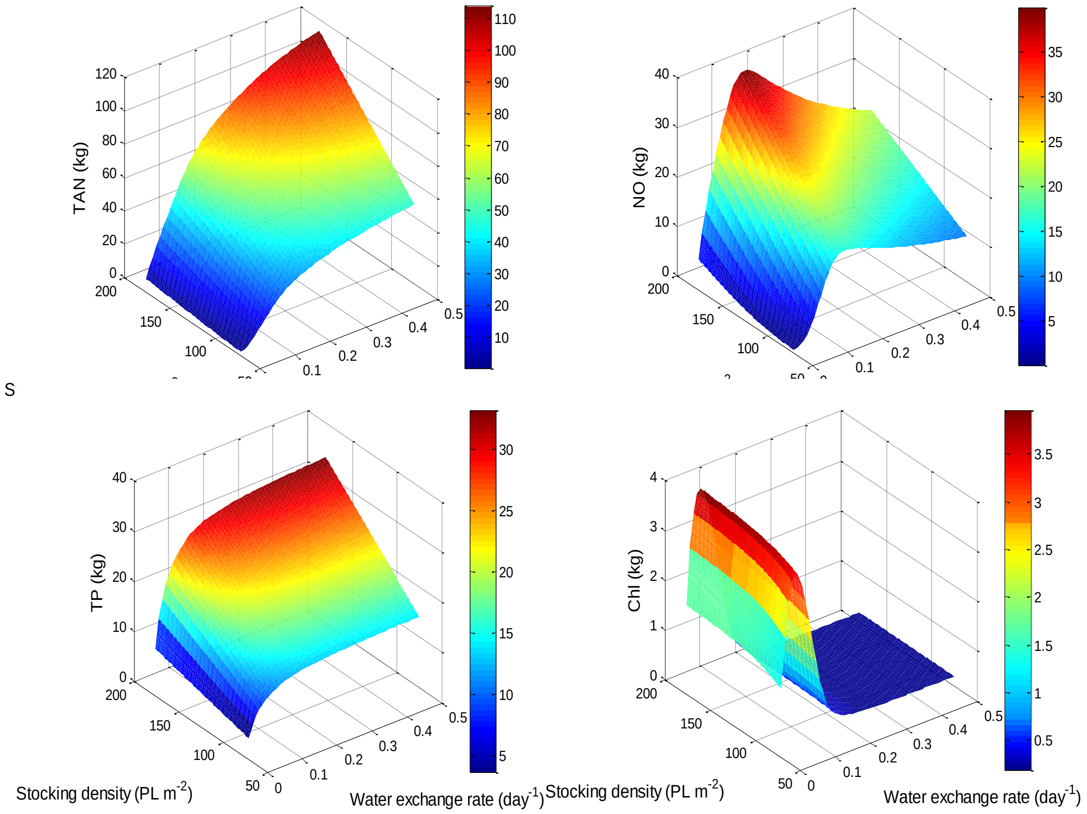

Figure 3. The combined effects of stocking density and water exchange on loading of TAN, NO, TP and Chl from a shrimp pond (pond size = 0.3 ha).

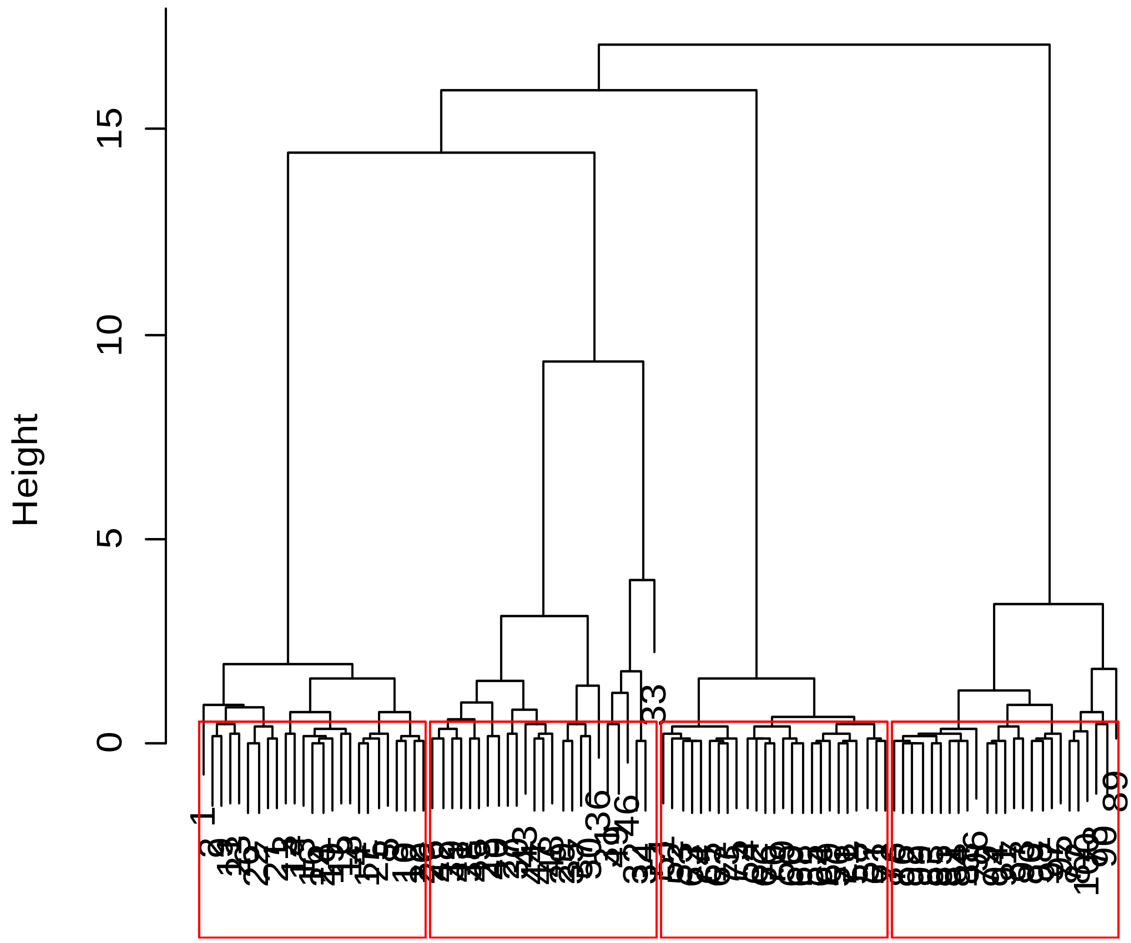

Figure 4. Hierarchical clustering dendrogram with red borders based on Ward's method for estimating numbers of clusters.

Agglomerative Coefficient = 0.99

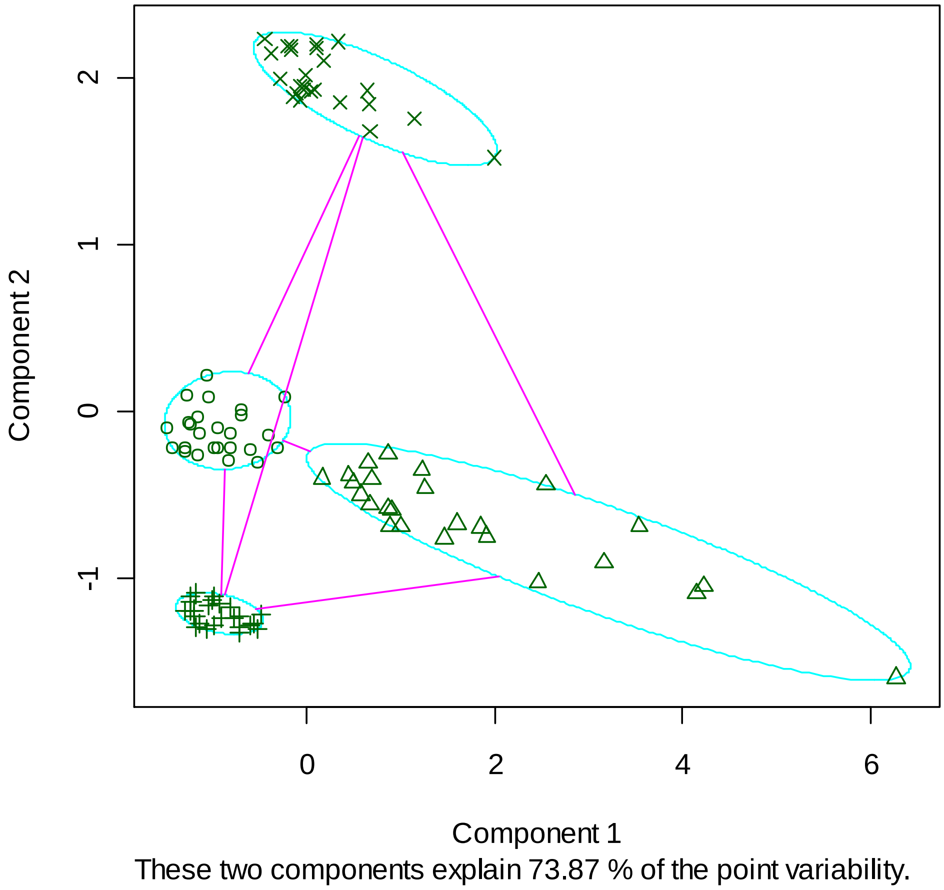

Figure 5. Cluster plot of 4-cluster solution based on non-hierarchical PAM method.

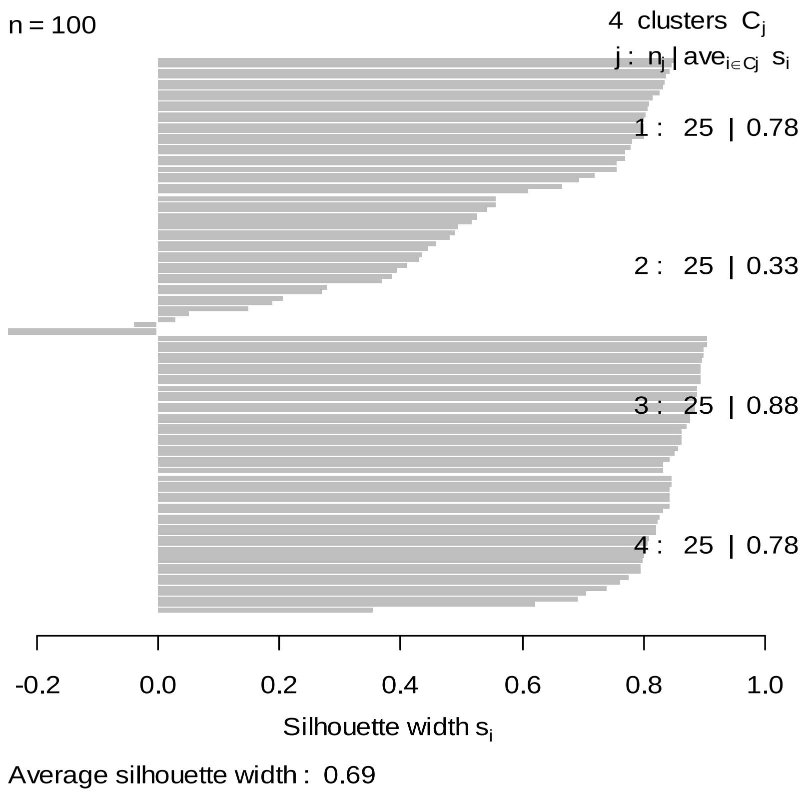

Figure 6. Silhouette plot of 4-cluster solution based on non-hierarchical PAM method

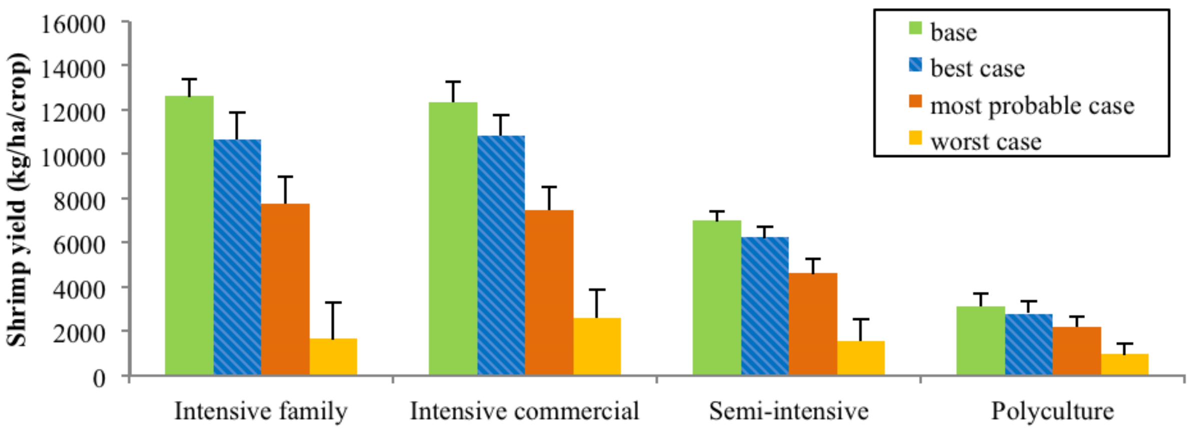

Figure 7. Effects of disease outbreak on shrimp yield given different disease levels (mean + S.D.)

Developing Management Recommendations for Freshwater Small-Sized/Low Value Fish in the Lower Mekong Region of Cambodia and Vietnam

Mitigating Negative Environmental Impacts/Study/09MNE04UC

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INTRODUCTION

Over the last decade, the price of small-sized/low value fish has risen considerably and it is predicted to increase over the next few years due to increased demand for fish meal and fish oil to meet market demands for aquaculture of carnivorous fish and well as a source of affordable human food (FAO-APFIC, 2005). At the local level, prices of small-sized/low value fish vary depending on species, seasons and abundance of other fish and fishery products. Prices also fluctuate with the demand for fish meal in the livestock and aquaculture industry and the availability of raw materials for fish meal production in the Lower Mekong basin (So Nam et al. 2009a; Le Xuan Sinh and Pomeroy, 2009; So Nam et al., 2007; So Nam et al., 2005). Given that aquaculture is predicted to grow while capture fisheries remain stable, it will become increasingly more difficult to meet the demand for small-sized/low value fish for human consumptions.

There is an increasing conflict between the use of small-sized/low value fish for animals/fish and for human consumption in the Lower Mekong River basin (Hap Navy and Pomeroy, 2009). Supplies of small-sized/low value fish are finite, and as indicated by a recent increase in price, i.e. demand is outstripping supply, due to mainly depletion of fish stocks resulting from overfishing, population growth and ecosystem degradation (So Nam et al., 2009; Le Xuan Sinh and Pomeroy, 2009). It has been argued that it would be more efficient and ethical to divert more of the limited supply to human food, using value-added products, etc (Un Sophea et al., 2010; So Nam et al., 2009b; So Nam et al., 2009c). Proponents of this suggest small-sized/low value fish as food for poor domestic consumers is more appropriate than supplying fish meal plants for an export income oriented aquaculture industry, producing high value commodities (Le Xuan Sinh and Pomeroy, 2009). On the other hand, food security can also be increased by improving the income generation abilities of poor people, and it can be argued that the large number of people employed in both fishing and aquaculture has this beneficial effect, via income generation, rather than direct food supply.

In general, the disposition of small-sized/low value fish is market driven and dependent upon local economic mechanisms in the Lower Mekong River basin. Without external interventions (such as incentives and subsidies) it will be the economics of the different uses of small-sized/low value fish in different localities that will divert the fish one way or the other. For example, in Viet Nam, as the national demand for fish sauce is predicted to double over the next 10 years, there appears to be direct competition for mixed small-sized/low value fish between *Pangasius* feeds and those needed to make low-cost fish sauce. Traditional small-scale pig, duck and chicken rearing uses small-sized/low value fish but large-scale pig, duck and chicken farming uses agro-industrial formulated feed containing fish meal (Le Xuan Sinh and Pomeroy, 2009).

Small-sized/low value fish are important to the local communities and aquaculture, as well as the wetland or floodplain ecosystems in Cambodia and Vietnam. Therefore there is a need to support the development of a policy and management framework to address aquaculture and capture fisheries interactions.

OBJECTIVE

The objective of this study is to develop management recommendations for freshwater small-sized/low value fish in the Lower Mekong region of Cambodia and Vietnam in order to reestablish stocks to support food security and poverty alleviation.

METHODOLOGY

This study was primarily a desk policy analysis. Significant data and information on the problem, issue, status of stocks, utilization, supply and demand trends and impacts were collected from other investigations of this project (Table 1) in order to a solid foundation for developing management plans and interventions. This investigation involved: (1) a re-analysis of all this data and information and (2) the development of fisheries management recommendations to conserve the biodiversity of freshwater small-sized/low value fish species in the Lower Mekong region. A series of stakeholder consultations with all relevant government and non-government organizations, research and academic institutions, and the private sector in both Cambodia and Vietnam were conducted to obtain additional information and to validate findings and recommendations (Table 2). In addition, other literatures in the Mekong River basin, especially in the Lower Mekong basin of Cambodia and Vietnam were also collected, reviewed and analyzed in order to develop a wise management recommendations for policy development and action plan for conservation and management of freshwater small-sized fish stocks in the Lower Mekong River basin of Cambodia and Vietnam.

RESULTS

Importance of freshwater fisheries in the Lower Mekong River basin

The Lower Mekong River basin, including parts of Cambodia, Lao PDR, Thailand and Viet Nam, support a significant fishery. Consumption of fish, including small-sized fish and other aquatic animals (OAAs) in the Lower Mekong River basin was estimated to be about 2.6 million tonnes by a population of about 60 million as fresh whole animal equivalents (Hortle, 2007). Annual consumption of inland fish plus OAAs as country averages varied from 41 to 52 kg per capita. When converted to protein units, aquatic foods basin wide accounted for about 49 – 82% of all animal protein consumption. Hence, inland fish and OAAs are most important in Cambodia and Viet Nam, whereas Lao PDR and Thailand have about equal contributions from aquatic foods and other animals.

Fish has long been critical to all Cambodian and Vietnamese people as well as other Mekong riparian countries. It is a major source of nutritious food in the daily diet, a primary source of income and has strong cultural and religious significance (So Nam and Touch Bunthang, 2011; Kurien et al., 2006). Fisheries matter a great deal to the millions of people who live on the banks of the country's rivers, particularly those living in and around the Tonle Sap Great Lake. Cambodians are considered one of the highest per capita consumers of freshwater fish in the world as the average freshwater fish consumption rate in Cambodia was 51.4 kg per person per year, including OAAs, while the average freshwater fish consumption rate in Vietnam was 48.7 per person per year (Hortle, 2007), which are in the mid-upper level of world ranges of 15 – 90 kg per person per year. Therefore, freshwater fish provided more than 80% of the total animal protein intake for the population, and contributed 6.2 to 8.0% of the Cambodia's total GDP in 2010 (So Nam and Srun Lim Song, 2011). Fisheries from the Cambodia's Mekong River basin contributed over 80 percent of the total annual fish catch in Cambodia, being equal to approx. 400,000 tonnes in 2010, including small-sized fish and juvenile of commercially important fish species (See the following sections); of which around 60% was from Tonle Sap (Table 3). Its value ranged from US$ 800 – 1,000 million (So Nam & Srun Lim Song, 2011).

Small-sized fish and freshwater fisheries- status and key issues

Small-sized fish species by definition generally has a maximal total length of equal to or less than 25 cm. They generally have at least 10-time lower market value than big-sized fish species. Therefore small-sized fish species are more acceptable by and accessible to the poor particularly in seasons of high production, which reflects the findings of Roos et al. (2007). Funge-Smith et al. (2005) defined low value fish as: "Fish that have a low commercial value by virtue of their low quality, small-size or low consumer preference. They are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fish meal/oil".

Small-sized fish catch

In Cambodia and Vietnam, inland fisheries are significant for local food security, household income, and export markets. Cambodia fishers operated more than 150 types of fishing gears (Hortle et al, 2004). Of which, the nine most common and popular middle-scale fishing gears were gill-nets, bamboo or nylon net traps, cast-nets, seine-nets, encircling seine-nets, deep drag-nets/trawls, pair trawls, giant lift nets, net fence system with pens/*bor* in Tonle Sap and Mekong River basin and their floodplains (So Nam et al., 2009a). The average fish catch was about 10 tonnes per fisher in 2008. This figure was declined from 19.7 tonnes per fisher in 2001, representing a decline of approx. 45% since 2001 (So Nam et al., 2009). Small-sized fish is the most dominant in the catch as the average proportion of small-sized fish catch in 2008 was about 88% of total fish catch, while the big-sized fish catch was about 12%. The trends of proportions of small-sized fish catch had increased since 2001, i.e. being an annual increase of about 10%. Of the small-sized fish catch, 38% was juvenile of big-sized or commercially important fish species. The trends of proportions of juvenile of big-sized fish had increased for the last eight years, i.e. increasing from about 20% in 2001 (So Nam et al., 2009a).

Bag-net '*Dai*' or stationary trawl fishery is, by law, one of the large or commercial scale fisheries in Cambodia, which filters the current, and is typically 25-45 m wide and 100 m long (Fig. 1). The operation of this commercial-scale bag-net fishery is subject to payment of annual fees for the national revenue. *Dai* fishery operates during receding floodwaters between October and March each year in Tonle Sap River to filter migratory fish species, particularly small cyprinids of the genus *Cirrhinus* (misidentified as *Henicorhynchus*; *Trey riel* in Khmer), migrating from the Great Lake floodplains, via Tonle Sap River, to the Mekong River. Within this timeframe, there are, normally, two peak migration periods, one being at the end of December or January and the other at the end of January or February each year. Each peak period lasts for 6 – 10 days before the full moon (Lieng, 2006). Based on the study of So Nam et al. (2009a) the average fish catch was 133.5 tonnes per *dai* in the 2007-2008 fishing season. The per *dai* fish catch had declined since 2000-2001 fishing season, i.e. a decline of about 36%. Of the total *dai* fish catch, 96.5% was small-sized fish species, while big-sized fish catch was about 4% (So Nam et al., 2009). This proportion of small-sized fish catch increased from 90.3% in 2000-2001, while the big-sized fish proportion decreased from 10% in the 2000-2001 fishing season. Of total big-sized fish catch in the 2007-2008 fishing season, 85% was juvenile of big-sized fish, which increased from 76% in the 2000-2001 fishing season.

The other commercial-scale fishing operation in Cambodia is based on 'lots', fishing areas which are auctioned every two years. Large-scale fishing gears are only permitted in fishing lots, which can only be fished in the open season (October to May in most areas). Such gears include fences with traps, and barrages. Fences, up to several kilometers in length, are built across flooded areas or lakes to direct fish into traps (Figure 2). Barrages are smaller gears that block a stream and direct fish into traps (Figure 3). The average annual fish catch of a fishing lot system was 337 tonnes per lot in 2008, decreasing from 554 tonnes in 2001 or a decrease of approx. 39% over the past 8 years. Of the total fish catch, small-sized fish catch is the most abundant (82%), while big-sized fish catch was 18% (So Nam et al., 2009). The figure of small-size fish catch increased from 74% in 2001 (being an increase of about 9%), while the figure of big-sized fish decreased from 26% in 2001(being a decrease of 9%). The proportion of fish catch of juvenile of big-sized fish was 32% of small-sized fish catch in 2008 and 28% in 2001, representing an increase of approx. 5% since 2001.

Hence, freshwater small-sized fish are the most abundant species in the total freshwater fish catch in Cambodia. The small-sized fish species keep increasing in the total fish catch over nearly a past decade, while the bid-sized or commercially important fish species keep decreasing since that time; this leads to overfishing in freshwater fisheries in Cambodia. The main reasons of overfishing are (1) population growth and increase in number of fishers; (2) use of illegal and destructive fishing methods such as brush parks, electro fishing gear, small mesh sized mosquito nylon nets and water pumping fishing method; and (3) wetland or floodplain ecosystems or habitats degradation. These reflect the findings of So Nam & Srun Lim Song (2001).

Freshwater fisheries in the Mekong Delta of Vietnam is less significant compared to Cambodia's ones and to its aquaculture sector. There were three major fishing grounds in freshwater water bodies in the

Mekong delta, consisting of rice field, rivers or public man-made canals, and ponds or garden ditches without aquaculture, which are located three flooding areas, shallow, medium and deep (Le Xuan Sinh and Pomeroy, 2009). One fishing gear might be used in one or different fishing grounds. The survey results showed that fishing on the rice field in flooding season was the most common (76% of the fishers), especially in the medium flood areas (81%). The next was fishing in rivers or public canals (41%), while fishing in the ponds or garden ditches without aquaculture was very rare (5%). At least, 14 types of fishing gears were reported in the Mekong Delta of Vietnam (Le Xuan Sinh and Pomeroy, 2009 Le Xuan Sinh et al., 2007), significantly lower that the figure found in Cambodia. The most common and popular fishing gears used in Vietnam were gill-nets, including three-layer gill nets or tremble nets (56%), trawl nets with or without combined with electro shockers (22%), and small mesh size nets (13%) (So Nam et al., 2009a; Le Xuan Sinh and Pomeroy, 2009). These types of fishing gears are very destructive and also illegal when electro shockers are combined, and can catch all fish species, with all sizes. The average annual fish production varied from 1.5 to 4.2 tonnes per household, excluding the catch of golden snails. Golden snails contributed significantly to the fishing production overall average, the households might catch more than 1 - 90 tonnes of golden snails per year. Trawl net had the highest yield (2.3 t/net/year), followed by trawl nets (1.8 t/net/year), and small mesh size set net (1.8 t/net/year). Note that the fish yield by fishing gears was also different by fishing grounds, flood scenarios and fish species, as well as the design of net and number of fishing days per year. The proportion of small-sized fish catch was 96% of the total fish catch, while the proportion of big-sized fish catch was 4%. The proportion of fish catch of juvenile of big-sized fish was 51% of the total small-sized fish catch. There was a significant decline of small-sized fish catch by 58% between 2001 and 2008, and of big-sized fish catch by 63% between both years.

The above fishing gears used in Cambodia and Vietnam are very effective and efficient that can capture all small-sized fish species, with all different sizes.

Small-sized fish species diversity

Small-sized fish species of the Lower Mekong River basin of Cambodia and Vietnam is very diverse. At least 200 inland small-sized fish species were found and identified, and their photographs were available (So Nam et al., 2009a; Le Xuan Sinh and Pomeroy, 2009). Many of these small-sized fish species are truly abundant. Trey riel in Khmer or Cá linh ria in Vietnamese (mainly *Cirrhinus siamensis* and *C. lobatus*) was the most abundant freshwater small-sized species in the Lower Mekong River basin of both countries Cambodia and Vietnam. The top ten small-sized fish species detected in the Mekong River basin in Cambodia were: Trey riel (*Cirrhinus spp.*), Trey srakar kadam (*Cyclocheilichthys armatus*), Trey khnag veng (*Labiobarbus lineata*), Trey kros (*Osteochilus microcephalus*), Trey slouek russsey (*Paralaubuca spp.*), Trey linh (*Thynnichthys thynnoides*), Trey kanhchrouk (*Yaasuhikotakia spp.*), Trey bandol ampil (*Clupeichthys aesarnensis*), Trey khampleanh phluk (*Trichogaster microlepis*), and Trey changwa (*Rasbora spp.*). These species make up to approx. 80% of total freshwater small-sized fish catch. In the Mekong Delta of Vietnam, the top ten small-sized fish species were Cá linh ria (*Cirrhinus spp.*), Cá linh (*Labiobarbus lineata*), Cá thiểu (*Paralaubuca spp.*), Cá rầm (*Puntius brevis*), Cá ba kỳ (*Cyclocheilichthys armatus*), Cá lòng tong (*Rasbora spp.*), Cá rô đồng (*Anabas testudineus*), Cá sặc bướm (*Trichogaster trichopterus*), Cá sặc rằn (*Trichogaster pectoralis*) and Cá rô biển (*Pristolepis fasciata*). These species contribute at 70% to the total freshwater small-sized fish catch. The estimate of freshwater small-sized fish catch in Cambodia is approx. 85% of the total freshwater fish catch, while the estimate in Vietnam is around 96%. Of the total freshwater small-sized fish catch, in Cambodia 35% were juvenile of big-sized or commercially important fish species, while in Vietnam 51% (So Nam et al., 2009a).

All freshwater small-sized fish species in the Lower Mekong River basin of Cambodia are not "trash" fish, and all are eaten by human, especially for the poor communities. Some freshwater small-size species have a high market value, e.g. Trey linh, Trey kanhchrouk, Trey kros in Khmer. All freshwater small-sized fish are either used for human consumption (often processed or preserved) or used for fish and livestock, either directly or through reduction to fish meal or oil.

Utilization and price of freshwater small-sized fish

Freshwater small-sized fish species were traditionally used in Cambodia and Vietnam for making fish sauce, *prahok* or *mum* (fermented fish paste; Un Sophea et al., 2010So Nam et al., 2009b; So Nam et al., 2009c; Le Xuan Sinh and Pomeroy, 2009), which is a vital protein source and favorable ingredient for most of the Cambodian population, particularly the rural poor during the closed fishing season and at the end of the dry season when fish are scarce (So Nam et al., 2009a; So Nam et al., 2007), leading to enhancement of fish food security of the local communities. The indigenous technologies of freshwater small-sized fish processing for bony and boneless fermented fish paste or *prohoc* production in Cambodia were documented in the study of So Nam et al. (2009b). It is a profitable business and the total production of fish paste keep increasing, although its main problem is poor hygiene quality and safety of fish paste. However, this problem has been being addressed by the Royal Government of Cambodia by the development of good manufacturing or hygienic practices, and quality and safety standards to meet national and international market requirements (Kao Sochivi and Pomeroy, 20011). In the Mekong Delta, the fish sauce production has been expanded over the past decades and the Vietnamese government in Viet Nam has set a target to double fish sauce production over the next 10 years (Le Xuan Sinh and Pomeroy, 2009), there appears to be direct competition of the use of freshwater small-sized fish for fish and other animal feeds and for producing low-cost fish sauce for human consumption.

Over the past two decades, small-sized fish were also utilized for feeding fish and other animals (Camber et al., 2008; Eldin-Lundgren et al., 2008; So Nam et al., 2005; So Nam & Nao Thuok, 1999) and now especially for feeding snakehead and *Pangasius* fish species in Cambodia and Vietnam (So Nam et al., 2009a; Le Xuan Sinh and Pomeroy, 2009). Based the recent study (So Nam et al., 2009), approx. 84% of total freshwater small-sized fish catch in Cambodia were used for human food consumption (fresh or processed); being 71% used in Cambodia and 13% exported to Vietnam and Thailand, while 16% were used for fish and animal feeds, including the export to Vietnam. This potential problem could be an increasing export of freshwater small-sized fish to Vietnam for the use of human food and fish and animal feeds, which will lead to a net loss of small-sized fish for the Cambodian people. This problem is also reported in the studies of Camber et al. (2008) and Eldin-Lundgren et al. (2008). Based on these three studies, it is concluded that freshwater small-sized fish used in Cambodia is approx. 80%, and exported is 20%. The proportions of freshwater small-sized fish used for human food consumption in fresh and processed forms, and the portions of small-sized used for animal and aquaculture feed cannot be separately quantified. So Nam et al. (2007) quantified the proportions of freshwater small-sized fish used for human consumption and fish/animal feeds only from freshwater small-sized fish harvested from *dai* or bag-net fishery along Tonle Sap River. The proportions are similar to the ones of So Nam et al. (2009a). Similar proportion of freshwater small-sized fish in Vietnam (72%) to the one (71%) in Cambodia was used for human food consumption Approx. 72% of the total freshwater small-sized fish catch was used for human food consumption. Approx. 15% was used for snakehead fish culture industry as direct feed, and 13% for direct animal feed (So Nam et al., 2009a). Hence, the key issues related to freshwater small-sized fish utilization are underpinned by the rapid development of the aquaculture industry, including the snakehead fish, and the increasing demand for fish by consumers, and strong competition between these two users in the Lower Mekong River basin of Cambodia and Vietnam.

Due to all the above key problems and issues: limited and declined freshwater small-sized fish resources, high competition between the use of freshwater small-sized fish for human food consumption and fish and other animal feeds, and demand outstripped supply lead to a significant increase in fish price in the Lower Mekong River basin of Cambodia and Vietnam (So Nam et al., 2009; Le Xuan Sinh and Pomeroy, 2009). In Cambodia, there was an average increase of approx. 6 times in price of freshwater small-sized fish over the past decade, while this growth rate was lower in Vietnam, being a 4-time increase in price of freshwater small-sized fish. This is probably due to freshwater aquaculture significantly developed in Vietnam and insignificantly developed in Cambodia over the past decade.

Impacts of snakehead culture

In May 2005, the government of Cambodia put a ban on snakehead farming and the reasons for this was the potential negative impacts on wild fish populations from wasteful snakehead seed collection and on other freshwater fish species diversity, including small-sized fish and juveniles of commercially important fish species, and also potential negative effects on poor consumer groups from decreased availability of small-sized fish (So Nam et al, 2007). So Nam et al. (2005) provided an estimation of 50,482 tonnes of freshwater small-sized fish (or approx. 13% of total freshwater fish production), which has been used for aquaculture, including snakehead, in 2004 in Cambodia. So Nam et al. (2009a) revealed that the ban did not only result in positive impacts on poor consumer groups from increased availability of freshwater small-sized fish in Cambodia, but also providing negative effects on livelihood of tens of thousands of snakehead farmers who depend on this livelihood for generating household income. In other words, these snakehead fish farmers have lost their important livelihoods and household income. Moreover, the ban also did not provide positive impacts on improvement of snakehead wild stocks as fishing pressure on wild snakehead using illegal and destructive fishing gears particularly electro-shockers has been increased for the recent years in order to supply local and external markets. In this sense, domestication breeding, and weaning and growing out the striped snakehead *Channa striata* using formulated diets was trialed on station at the hatchery of Freshwater Aquaculture Research and Development Center (FARDeC) in Cambodia, and these technologies were transferred from College of Aquaculture and Fisheries of Can Though University, Vietnam through trainings and demonstrations (See the below section). In Vietnam, the production of 30,000 tonnes of snakehead in 2009 (Le Xuan Sinh and Pomeroy, 2009) and 40,000 tonnes in 2010 (Le Xuan Sinh and Pomeroy, 2011) were produced by mainly using small-sized fish as direct feed. If the FCR is 4, 120,000 tonnes of small-sized fish in 2009 and 160,000 tonnes in 2010 were used for feeding the snakehead, representing 17% and 23% of total annual freshwater fish production in the Mekong Delta of Vietnam in 2009 and 2010, respectively. As a result, snakehead farmers in the Mekong Delta of Vietnam lost profit due to high feed cost (> 75%; Le Xuan Sinh and Pomeroy, 2009; Tran Thi Thanh Hien and Bengtson, 2011), and disease outbreaks caused by 23 genera of parasites, 4 genera of fungi, and 81 strains of bacteria belonging to 5 genera (Pham Minh Duc et al., 2011). In this sense, formulated feed development and weaning of snakehead *Channa striata* and *C. micropeltes* using formulated feed were trialed on station and on farm by College of Aquaculture and Fisheries of Can Though University, Vietnam (See the below section).

Domestication breeding, and weaning and growing out striped snakehead *Channa striata* using formulated feed in Cambodia

So Nam et al. (2011) demonstrated that the wild striped snakehead *Channa striata broodstocks* can successfully be developed, mature and semi-artificially induced spawning using HCG at doses of 1,000 IU.kg^{-1} for female fish and 3,500 IU.kg^{-1} for male fish at the hatchery of Freshwater Aquaculture Research and Development Center (FARDeC), Cambodia. The male fish received 2-3 injections within 2-3 days before the female fish, which was received only 1 injection. With this optimal HCG doses, the spawning success was 100%; spawning time after the last injection of female and male fish was 9 hours; number of eggs spawned per kg female was 32,000; the fertilization rate was 87%; hatching rate was 73%; and the larval production and survival rate was 21,000 larvae per kg female and 72%, respectively. This has very important implications for protecting snakehead wild stocks from a wasteful collection of snakehead seed from the wild.

The striped snakehead *Channa straita* aging 30 days old after hatch could gradually and successful accept formulated feed in replacement of small-sized fish in the rate of 10% every three days for a period of 30 days of feeding, and then be successfully grown out with a complete 40% crude protein pellet feed for a period of ten months to achieve a final weight of 314 g.fish^{-1}, a survival rate of 56%, and a FCR of 1.68 (So Nam et al., 2011). The F_1 broodstocks which could accept formulated or pellet feed are available for future domestication breeding and weaning at FARDeC, Cambodia. This has very important implications for protecting freshwater small-sized fish, which are usually fed to snakehead, and will eventually lead to list the snakehead ban in Cambodia.

Formulated feed development and weaning and growing out of snakehead fish in Vietnam

The formulated diets used for weaning snakehead larvae, rearing fingerlings and for growing out are successfully developed at laboratory and hatchery of College of Aquaculture and Fisheries, Can Tho University, Vietnam. Tran Thi Thanh Hien and Bengtson (2009) reported weaning of snakehead larvae with 50% crude protein formulated feed could begin by 17 days after hatch with the replacement ratio of 10%.day^{-1}. Up to 40% of fish meal used in formulated diet for *Channa striata* and *Channa micropeltes* fingerling could be replaced by soybean meal, with phytase supplements and showed insignificant loss of growth performance, feed utilization and survival rate of the two snakehead species. Rice-bran could be well utilized by snakehead fingerlings with levels from 10% to

30%, without any differences in growth performance and carcass composition. Hence, rice bran could be used as home-made formulated feed for snakehead fingerlings up to 30% to reduce feed cost. Soybean meal can replace up to 60% of fish meal in the diet with the addition of phytase and alpha-galactosidase or fish solution feeding attractant. However, considering economic efficiency, protein soybean meal only can replace up to 50% of protein fish meal in the diet with the addition of phytase and alpha-galactosidase or fish solution feeding attractant.

Considering economic efficiency, replacing freshwater small-size fish by formulated feed in the two snakehead species diets up to 100% is possible (Tran Thi Thanh Hien and Bengtson, 2009). If both growth performance and feed efficiency ratio were interested, the replacement should stop at 50%. Thus, depending on a farmer's situation, they should choose optimal solution for replacing fresh water trash fish by formulated feed in snakehead culture. *C. micropeltes* and *C. striata* fillet quality in a taste test was fairly liked and did not significantly differ between samples. In descriptive pair tests, there were no significant difference between samples. Thus, formulated feed (fish meal or plant protein) did not significantly affect the quality of fish fillet in both *C. micropeltes* and *C. striata* compared to a diet of freshwater small-sized fish.

Based on the results from on-farm trials conducted using hapa culture system in An Giang and Dong Thap province, the striped snakehead *Channa striata* was successfully grown with formulated feeds of 44%, 41% and 38% crude protein developed Can Tho University, and showed insignificant loss of growth performance, feed utilization and survival rate, while it was unsuccessful with the giant snakehead *Channa micropeltes* (Tran Thi Thanh Hien and Bengtson, 2011). Interesting, the striped snakehead fed with formulated feeds showed slightly higher profit than fish fed with freshwater small-sized fish. This has very implication for protecting freshwater small-sized fish stocks and reducing environmental impacts. As a result from the research and trials, now at least seven fish manufacturing companies are developing and trialing their snakehead formulated diets in the Mekong Delta of Vietnam. Of which four companies are very active and advanced: AquaFeed, Ca Vang, Cargill and UP.

CONCLUSIONS AND RECOMMENDATIONS

1. The capture fisheries of Lower Mekong River basin in Cambodia and Vietnam are overfished due to illegal and high fishing pressures, population growth, and floodplain or wetland ecosystem degradation. Therefore the freshwater small-sized fish production, which contribute more than 80% to the total freshwater captured fisheries in the Lower Mekong River basin of Cambodia and Vietnam and are used and important for human food consumption, fish, including snakehead fish, and other animal feeds, and aquatic or wetland ecosystems, are scarce or limited, although the biodiversity of freshwater small-sized fish species is rich (at least 200 species). Capture fisheries are not the major threat to biodiversity in rivers – aquatic environmental or ecosystem degradation is.
2. Understanding the role of ecosystem variability (including hydrology) in sustaining the Lower Mekong's rich biodiversity is crucial. Development activities in a river system almost always result in the simplification, or even obliteration, of ecosystem diversity. These disturbances appear to be by far the greatest threat to sustaining aquatic biological resources in Lower Mekong River basin.
3. The important role that river floodplain fisheries play in maintaining aquatic biodiversity must be promoted more widely. All sectors should cooperate in integrated water resources management (i.e. IWRM approach).
4. The waters of the Mekong and its tributaries could be put to many uses: irrigated agriculture, potable domestic supply, hydroelectricity production, navigation and fisheries. In Cambodia, fisheries production is primarily from the wild capture fishery. Developments in other sectors will become increasingly common in the future and the wild fishery is likely to decline as a consequence. Actions to mitigate and manage the impacts of water management projects will minimize this decline; such actions depend upon an effective engagement of fisheries managers with planners in other sectors. Only through this approach can we have truly sustainable development for the people using the resources of the Mekong.

5. Emphasizing the importance of fisheries of small-sized fish species to livelihoods and food security provides the strongest and most relevant argument for improved management of the aquatic environment.
6. Fisheries activities can have negative impacts upon biodiversity. Improved management of law and regulation enforcement, and exploitation, by moderation the use of unsustainable fishing practices such electro fishing, small mesh size net fishing, brush-park fishing and pumping fishing method, should centre on the promotion of co-management approaches to decentralization of fisheries management (i.e. dialogue between local resource users, government authorities, scientists and other stakeholders on management needs and methods in order to reduce the impacts of illegal fishing and overfishing.
7. Management initiatives need to be prioritized and adaptive, focusing on those species and habitats under greatest threat and basing on scientific research and monitoring data and local ecological knowledge. Recent experience has shown a high level of agreement between local ecological knowledge and fisheries science.
8. The use of local ecological knowledge as both a research tool and a mechanism for improving participation in management should be promoted more widely. There should be increased recognition of the importance of this knowledge base for biodiversity-related subjects.
9. The fishing "lot" system of floodpain fisheries and river *dai* fishery in Cambodia should be properly and scientifically evaluated to determine if it is an effective tool for sustaining biodiversity. Studies should include consideration of whether social equity and sustaining biodiversity are necessarily mutually exclusive. There is considerable interest internationally in this system as a way of improving environmental management.
10. Freshwater fish protected areas, dry season refuge ponds, and channel for migrating fish on floodplains should be maintained or scientifically identified and established in fishing “lot” areas, community fisheries areas, and floodplain rice-fields, and an adaptive plan for managing these protected areas should be developed and implemented to protect and enhance stocks or populations of this rich biodiversity.
11. Development planning should recognize the value of fisheries and their importance in the livelihoods of Cambodian and Vietnamese people.
12. Environmental Impact Assessments should consider all options for development, as well as the costs and benefits of competing uses of water.
13. Plans for water management projects should include consideration of sustaining, and where possible, increasing fish production.
14. The main elements of the flooding cycle and important fish habitats should be maintained where possible; if water management projects are designed to reduce flood levels then the consequences for fisheries production should be appraised and appropriate substitutes for livelihoods and income for those affected should be available.
15. Any evaluation of dams proposed for the Mekong mainstream and major tributaries should consider the consequences for fish migrations and floodplain production downstream, and should recognize that impacts could not be fully mitigated.
16. Mitigation measures should be incorporated in the design and operation of dams, including low-level weirs; these could include fish passes, maintenance of riparian flows, re-regulation of discharges and measures to improve water quality.
17. Dialogue should be maintained between LMB countries on mitigating transboundary impacts from water management projects, fishing activities and exotic species, both up-and downstream of Cambodia and Vietnam. Where migration routes cross national borders, fish stock management becomes a trans-boundary issue and requires international collaboration.
18. The emphasis might be on developing appropriate procedures for cooperation at the international level in harmony with national and local management initiatives. The best opportunities are with the high profile migratory fish species and the vulnerable habitats such as the flooded forests and the deep pools where a consensus already exists on the need for action.
19. More information is required on the ecology (e.g. migration and spawning sites and behaviors), population genetics (e.g. stocks), and value and importance for livelihoods of the Lower Mekong River fisheries of Cambodia and Vietnam. But enough is known to provide clear directions for management of theses freshwater fisheries. It is time to adopt an integrated approach to conserving and enhancing fisheries for the continuing well-being of Cambodia and Vietnam and their neighboring countries.

20. Macro-habitat requirements are known for a few species in broad categories such as floodplain habitats and deep pools. However, micro-habitat requirements are unknown for most species. For example, even if it is known that a certain species lives in deep pool habitats during the dry season, the habitat features that the species require within the deep pool (type of substrate, vegetation, depth, slopes, current etc.) are unknown. Such micro-habitat requirements determine types of pools certain fishes prefer and indirectly determine other ecological characteristics including migration patterns.
21. Feeding biology for most species is related to the micro-habitat issue since availability of food (for example on the floodplain) determines the preferred floodplain micro-habitat.
22. A more attainable short-term goal is to promote changes to land classification systems, which are the basis for both natural resources planning and asset allocation. The current system suffers from a bias toward dry-season agricultural uses of land. It appears that legal systems are ill equipped to deal with assets undergoing dynamic changes especially for seasonal wetlands. Wetlands rarely have any legal status and are usually regarded as open access areas during the flood season. Converting these areas to agricultural use would not necessarily be more efficient biologically but it would enhance people's security of access and ownership. The legal status of wetlands and related institutional limitations are already recognized as constraints in achieving sustainability of fisheries and other natural resources.
23. Aquaculture production, including snakehead fish over nearly past ten years in Cambodia and Vietnam has rapidly expanded and continued expansion of aquaculture will contribute significantly to meeting the anticipated demand for fish products in the coming decades, although the difficulties in meeting anticipated demand are considerable.
24. Aquaculture, capture fisheries and reservoir management should be considered as a holistic system. Concentrating policy and development efforts towards aquaculture, as an 'easy option' for fish production, without taking proper care of the wild fisheries could result in a dramatic loss of wild fisheries resources, with food security implications for the Lower Mekong Basin of Cambodia and Vietnam, particularly for poor people. Similarly, aquaculture and fisheries are strongly influenced by the development of other sectors. A balanced approach to fisheries development is required.
25. Aquaculture can have the greatest impact on rural households in areas with food insecurity and limited wild fish supplies. The approach to supporting food security and livelihoods should be based on identifying these areas and supporting local area development, which may be aquaculture or wild fisheries activities or a combination of both. Therefore establishment and implementation of an action plan for development of aquaculture of indigenous Mekong fish species, including genetic knowledge and information, which are less dependent on freshwater small-sized fish as direct feed (e.g. omnivorous and herbivorous fish species), should be encouraged and supported by public and private sector and non government or civil society organizations.
26. Further research and development of formulated diets and domestication breeding, weaning and growth-out technologies for sustaining snakehead aquaculture in Cambodia and Vietnam should be a joint effort and support among public and private sectors, research and academic institutions, non-government organizations and snakehead farmers. The demand of freshwater small-sized fish is outstripping supply, so these fish should be important for local communities’ food consumption and for maintaining aquatic biodiversity and ecosystems.
27. Golden snails are so abundant in all rice fields of the Mekong Delta and harmful to rice production. Research on snakehead aquaculture using golden snails as a source of protein should be encourages and supported. This will have very important implications for reducing environmental and economical impacts caused by golden snails.
28. There are several constraints to sustainable development of snakehead aquaculture, especially in Cambodia, that will have to be addressed. Many of these are institutional rather than technical. The existing capacity and resources of government institutions for participatory extension and research is relatively weak and manpower is limited. Therefore, capacity building is required to support this approach. New partnerships going beyond traditional aquaculture extension are needed. The policies to support an integrated approach to aquaculture are not yet in place. There is a need to develop enabling policies to support the approach, but this will take time.
29. Diversification of rice farming systems using omnivorous or herbivorous indigenous Mekong fish species and integrated pest management, including economics and livelihood impacts of farming options and practices.

30. Reducing risks to rural livelihoods from aquatic animal diseases is one of the priority areas for sustaining snakehead aquaculture in Cambodia and Vietnam.
31. An efficient low-cost contingency plan for fish health management may also be established on a catchment as well as transboundary basis. Plans should be prepared for the containment and treatment of fish disease including the prevention of trade in live fish and movement of fry, fingerlings and breeders from a catchment area or cross border or transboundary area where an outbreak has been detected.
32. Further maximization of the utilization of freshwater small-sized fish for human Consumption through improving quality standard and safety with appropriate value added product development (e.g. fermented fish paste in Cambodia and fish sauce in Vietnam).
33. More information is needed on the trade of freshwater small-size fish and fish products, including snakehead fish within the basin and exports and imports to and from the basin.

ACKNOWLEDGEMENTS

This study was funded by AquaFish CRSP. We thank the Cambodia's Fisheries Administration, Fisheries Administration Cantonments of Phnom Penh, Kampong Cham, Prey Veng, Kandal, Prey Veng, Kampong Chnang, Battambang and Siem Reap in Cambodia, and provincial departments of rural development and fisheries in Dong Thap, Can Tho and An Giang in Vietnam for their field support and collaboration. We thank colleagues, field researchers and graduate and under graduate students of Inland Fisheries Research and Development Institute (IFReDI) in Phnom Penh and College of Aquaculture and Fisheries, Can Tho University in Vietnam for collecting field data and data entering and analysis.

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Figure 1 One row of commercially fishing bag-net '*Dai*' operated in Tonle Sap River, Cambodia, catching more than 95% of small-sized fish species (Photo by: FEVM Component of the MRC Fisheries Program).

Figure 2 Fence, with traps, a fishing lot system in Tonle Sap Lake, Cambodia

Figure 3 A barrage fishing system in Tonle Sap, Cambodia

Table 1 The 2007-2009 and 2009-2011 investigations of AquaFish CRSP USAID Grant No.: EPP-A-00-06-00012-00 in Cambodia and Vietnam

Investigation code	Investigation title	Host country principal investigator
07MER01UC	Competition and impacts between use of low value/trash fish for aquaculture feed versus use for human food	Le Xuan Sinh and Hap Navy
07MNE01UC	Assessment of diversity and bioecological characteristics of low value/trash fish species	So Nam
07SFT01UC	Alternative Feeds for Freshwater Aquaculture Species	Tran Thi Thanh Hien
07TAP01UC	Feed Technology Adoption and Policy Development for Fisheries Management	Prum Somay and Le Xuan Sinh
07FSV01UC	Maximizing the utilization of low value or small size fish for human consumption through appropriate value added product development	So Nam
09SFT01UC	Alternative Feeds for Freshwater Aquaculture Species	Tran Thi Thanh Hien
09IND02UC	Sustainable snakehead aquaculture development in the Lower Mekong River Basin of Cambodia and Vietnam	So Nam and Tran Thi Thanh Hien
09TAP03UC	Development of Alternatives to the Use of Freshwater Low Value Fish for Aquaculture in the Lower Mekong Basin of Cambodia and Vietnam: Implications for Livelihoods, Production and Market	Prum Somany
09FSV01UC	Maximizing the utilization of low value or small size fish for human Consumption through improving quality standard and safety with appropriate value added product Development: case study on fermented fish paste in Cambodia.	Kao Sochivi
09MER04UC	Value chain analysis of snakehead Fish in the Lower Mekong Basin of Cambodia and Vietnam	Le Xuan Sinh and Hap Navy

Table 2 A series of stakeholder consultations with all relevant government and non-government organizations, research and academic institutions, and the private sector in both Cambodia and Vietnam

No.	Workshop/meeting	Date and venue	Participants
1.	Stakeholder consultation workshop on validation of investigation research findings and recommendation for freshwater small-sized fish management in the Cambodia Mekong River basin.	11 March 2011, Inland Fisheries Research and Development Institute IFReDI, Phnom Penh, Cambodia	(1) provincial government fisheries officers in Kampong Cham, Prey Veng, Kandal, Phnom Penh, Kampong Chnang, Battambang and Siem Reap provinces in Cambodia, (2) non-government staff: WWF, CI, FAO, FACT, CEPA, JICA, DANIDA, IUCN, WCS and MRC, (3) Royal University of Agriculture and Prek Leap National School of Agriculture, and (4) fishers and fishing lot owners
2.	Consultation and training workshop on "Importance and Use of freshwater small-sized fish in the Lower Mekong basin of Cambodia and Vietnam, and policy management development and dialogue for freshwater small-sized fish in the Lower Mekong of Cambodia"	11-12 May 2011, Inland Fisheries Research and Development Institute (IFReDI), Phnom Penh, Cambodia	Government fisheries managers and officers, university faculty deans and staff, and R & D researcher and research managers
3.	Consultation and training workshop on "Importance and Use of freshwater small-sized fish in the Lower Mekong basin of Cambodia and Vietnam, and policy management development and dialogue for freshwater small-sized fish in the Lower Mekong of Vietnam"	8 July 2011, Can Tho University, Vietnam	Government fisheries managers and officers, university faculty deans and staff, and R & D researcher and research managers

Table 3 Trends of annual fish production in Cambodia (2001-2010)

Year	Total	Freshwater fish catch	Tonle Sap Great Lake	Marine fish catch	Aquaculture production
2001	441,000	385,000	231,000	42,000	14,000
2002	420,750	360,300	216,180	45,850	14,600
2003	382,000	308,750	185,250	54,750	18,500
2004	326,635	250,000	150,000	55,800	20,835
2005	410,000	324,000	194,400	60,000	26,000
2006	516,500	422,000	253,200	60,500	34,000
2007	493,760	395,000	237,000	63,500	35,260
2008	470,100	365,000	219,000	66,000	39,100
2009	516,910	390,000	234,000	75,000	51,910
2010	550,711	405,000	243,000	85,711	60,000

The Impact of Fish Stocking on Wild Fish Populations, Fish Production and Aquatic Environment in Irrigation Reservoirs in South Vietnam

Mitigating Negative Environmental Impacts/Study/09MNE05UM

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ABSTRACT

The southeast of Vietnam is characterized by uphill geography with hundreds of small and medium reservoirs (10-400 ha) built for irrigation. This study aimed to assess the impact of fish stocking on wild fish populations, fish production, and aquatic environments in 8 irrigation reservoirs. These reservoirs included 3 without stocked fish (Bau Um, Suoi Lai and Hung Phu reservoirs in Binh Phuoc Province) and 5 with aquaculture practices (Dong Xoai, Sa Cat Reservoirs in Binh Phuoc Province and Cau Moi, Da Ton and Gia Ui Reservoirs in Dong Nai Province). The areas of Bau Um, Suoi Lai, Hung Phu, Dong Xoai, Xa Cat, Cau Moi, Da Ton and Gia Ui are 60, 30, 18, 450, 45, 273, 350 and 320 ha, respectively. Bimonthly surveys were carried out in Dong Nai Province since July 2010 and Binh Phuoc Province since August 2010 to estimate the total catch and fish species composition. In addition, bimonthly field sampling was also done at Cau Moi stocked reservoir since July 2010 and Bau Um non-stocked reservoir since August 2010 to measuring water quality and to estimate the biomass (in dry weight) of natural food webs including phytoplankton, zooplankton, benthos, detritus, terrestrial plants and main fish species groups. At the end of the sampling year in August 2011, Ecopath 5.0 models were constructed to evaluate the stocking rate and fisheries carrying capacity for each reservoir. The results indicated the necessity to manage fish stocking and wild fish populations in reservoirs for better utilization of aquatic resources, thus enhance sustainable development. In stocked reservoirs, fish production was higher and at times water quality was lower. Increased stocking rates must be controlled to maintain adequate water quality, and the utilization of land surrounding the reservoirs may also affect water quality in reservoirs. Specific information on the impacts of cultured fish species on fisheries and natural food resources allow governmental agencies and local communities to establish policies, plans and mechanisms for management of stocking of cultured fish species.

INTRODUCTION

Exotic species are defined as species or subspecies introduced outside their natural past or present distribution. These introductions include any materials, such as gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (Bartley and Fleischer, 2005). Among reasons for introduction of exotic aquatic animals, aquaculture development is a major motive (Welcomme, 1998). The introduction of exotic aquatic species into a new region may cause not only environmental and socio-economic effects, but also be associated with “genetic pollution” (Cripps and Kumar, 2003). Invading exotic species in the United States cause major environmental damages and losses adding up to almost $120 billion per year (Pimentel et al., 2005). The introduction of exotic species into a new region will risk damage to native fish communities through predation, competition for habitats and food, disease, hybridization and other adverse environmental impacts (Welcomme, 2001; Cripps and Kumar, 2003), and can also produce imbalances in the fish community, disrupting food chains, and threatening the survival of non-target species (Welcomme, 2001).

The southeast of Vietnam is characterized by uphill geography. To support agriculture in this area, more than 50 small reservoirs (from 10 to 50 ha) and about 10 medium reservoirs (200 – 400 ha) were built for irrigation. In Binh Phuoc and Dong Nai provinces, many surrounding communities make use of the large water area (<50 ha) by stocking cultured fish species into reservoirs. This has been hypothesized as damage to natural fish populations, but there are no formal analyses about that and no evidence on reasons for these changes. Moreover, there has been no evaluation of the impact of water quality from reservoirs used for fish culture on the use of that water for irrigation.

Tilapia, bighead carp, silver barb, common carp and grass carp (all scientific names of fishes are in Appendix 2) are non-indigenous species stocked into big reservoirs like Tri An Reservoir (Luong et al., 2004) in south east Viet Nam. These species may compete for food and habitat but also serve as prey of native existing species (Luong et al., 2004). Previous CRSP project results have shown that the interaction among aquatic flora and fauna in Tri An Reservoir is very complicated, due to the varying fishery harvest, the continual input of new species, and the large size of the reservoir. However, using methodologies from Tri An studies, especially Ecopath modeling, it should be feasible to estimate carrying capacity, stocking rate and species composition of smaller reservoirs. These studies will estimate the degree and extent of damages on fisheries and biodiversity of indigenous fish species due to the introduction of cultured fish species in small reservoirs.

MATERIALS AND METHODS

The study was carried out at 8 small reservoirs in South Vietnam. These reservoirs include 3 without stocked fish (Bau Um, Suoi Lai and Hung Phu reservoirs in Binh Phuoc Province) and 5 with aquaculture practices (Dong Xoai and Sa Cat reservoirs in Binh Phuoc Province and Cau Moi, Da Ton and Gia Ui reservoirs in Dong Nai Province). The areas of Bau Um, Suoi Lai, Hung Phu, Dong Xoai, Sa Cat, Cau Moi, Da Ton and Gia Ui reservoirs are 60, 30, 18, 450, 45, 273, 350, and 320 ha, respectively. Bimonthly surveys have been carried out in Dong Nai Province since July 2010 and Binh Phuoc Province since August 2010 to estimate total catch and fish species composition at studied reservoirs.

For field sampling, one stocked reservoir and one un-stocked reservoir were selected. Bimonthly field sampling was conducted at Cau Moi reservoir (stocked) since July 2010 and Bau Um Reservoir (un-stocked) since August 2010 to measure water quality and to estimate biomass (in dry weight) of natural organisms including phytoplankton, zooplankton, benthos, detritus, terrestrial plants and the main fish species.

To determine biomass for phytoplankton and zooplankton, water samples were collected at 09:00-10:00h at nine stations in each reservoir. Concentration of chlorophyll *a* was measured using the spectrophotometric method (APHA et al., 1985), and the dry weight (DW) of phytoplankton was calculated by multiplying the content of chlorophyll a by a factor of 67 (Creitz and Richards, 1955). Zooplankton was concentrated from 50-L water sample by filtering through a 25-μm net, and fixed by 4% formalin solution. The zooplankton within 125 selected grids of a Sedgewick-Rafter counting cell were counted, and their size measured. The frequency of zooplankton size distribution was then calculated. The dry weight of zooplankton was determined by converting estimated length of zooplankton to biomass using length-weight relationship (Dumont et al., 1975; McCauley, 1984).

In Ecopath models, phytoplankton biomasses were converted from g DW/m^3 to g DW/m^2 by multiplying total volume of the photic zone, and then dividing for total area of the reservoir. Zooplankton biomasses was converted from g DW/m^3 to g DW/m^2 by multiplying total volume of the reservoirs, and then dividing for total area of the reservoir. The volume of the photic zone was estimated as the area of the reservoir within the depth range of twice the Secchi disk value.

Benthos was sampled at nine stations in each reservoir, with seven replications at each station, using an Ekman dredge with an area of 225 cm^2. Species abundance and biomass of benthos were quantified. The biomass was measured in ash-free dry weight. Due to the large amount of inorganic material included in some benthic organisms, benthos was dried at 105 C for dry weight determination, then it was ignited at 550 C for 4 hrs to estimate ash-free dry weight (Wetzel and Likens, 1979).

Sediment and bottom soil samples were collected from the top 5-cm layer of sediments at the nine stations in each reservoir for detritus biomass determination in terms of organic matter content (g DW/m^2). Benthos was separated from the sediment by a sieve. There was no periphyton growing on the sediments. Air-dried sediment samples were analyzed for the determination of organic matter content using the dry ash method (Boyd, 1995).

Terrestrial vegetation was surveyed at ten randomly selected plots (1x1m quadrats) in the littoral drawdown area when the reservoirs were at low levels from July to August 2010. Vegetation was categorized into three groups according to the trunk size and height of vegetation. Calculation of relative abundance (%) of species groups within a given area was carried out along 60-m long transects. Ground vegetation was harvested twice monthly for identifying species and estimating biomass on dry weight basis, done by drying in an oven at 105 C for 24-48 hours (Whittaker and Marks, 1975). The net production was equal to the observed change in biomass (Westlake, 1963).

The biomass of different fish groups (stocked fish, carnivorous wild fish, and herbivorous wild fish) was assessed. The stocked fish biomasses were calculated as the mean of the biomasses at stocking and at harvest, while the wild fish biomass was estimated from the survey of fish harvest and the availability of natural food. The biomass estimate was made on a dry weight basis obtained at temperatures at 103^0C (Winberg, 1971).

At the end of the sampling year in August 2011, Ecopath 5.0 models were constructed to evaluate stocking rate and fisheries carrying capacity for each reservoir (Christensen et al., 2000). In the models, energy flows of terrestrial plant, detritus, phytoplankton, zooplankton, benthos, and main fish species (stocked fish, carnivorous wild fish, and herbivorous wild fish) were quantified. The foundation of Ecopath is to create a static mass-balance snapshot of the resources in an ecosystem and their interactions, represented by trophically linked biomass boxes. An average model to represent the one year period was constructed for each reservoir. To construct the models, main input values included: (1) The average biomass in habitat area (B); (2) Production/biomass ratio (P/B); (3) Consumption/biomass ratio (Q/B); (4) Production/consumption ratio (P/Q); (5) Diet composition (DC). While the biomass (B) was measured directly in this study, other input values were referenced and calculated from the Ecopath model.

Ecotrophic efficiency (EE) is the proportion of production that is used in the system (i.e. either passed up the food web, used for biomass accumulation, migration, predation mortality, or export). This value varies between 0 and 1, and can be expected to approach 1 for groups with considerable predation pressure. According to Ricker (1971), the EE value is often assumed to range from 0.65 to 0.95. In this study, this parameter was calculated by the Ecopath program and then it was considered as one of the most important diagnostics for balancing the model and for predicting fish stock composition at the studied reservoirs.

RESULTS

1. Water quality and biomass at Bau Um and Cau Moi reservoirs

At Cau Moi reservoir (stocked), water quality parameters were collected from Upstream, Midstream and Downstream stations in the reservoir (Appendix 1). The results showed that total NH_3 concentration ranged from 0.037-0.742 mg/L, NO_2 from 0.002-0.006 mg/L, total phosphorus from 0.007 – 0.212 mg/L, DO from 4.4 – 5.5 mg/L, pH from 7.2 – 7.7, total alkalinity from 46.67 – 63.67 mg $CaCO_3$/L, temperature from 29 – 29.8^0C, and transparency from 75 - 85 cm.

At Bau Um Reservoir (not stocked), water quality parameters were also collected from Upstream, Midstream and Downstream stations and analyzed (Appendix 1). The results showed that total NH_3 concentration ranged from 0.00-0.27 mg/L, NO_2 from 0.000-0.003 mg/L, TP from 0.003- 0.059 mg/L, DO from 3.9-5.2 mg/L, pH from 6.80-7.16, total alkalinity from 19.33–31.67 mg $CaCO_3$/L, temperature from 28–29^0C, and transparency from 90-110 cm.

Phytoplankton biomass ranged from 1.17-1.97 g DW/m^3 during July-May at Cau Moi (Table 1), and from 0.21-1.47 g DW/m^3 during August-June at Bau Um Reservoir (Table 2). Phytoplankton biomass at the downstream station was significantly lower than at the upstream and midstream stations for both Cau Moi and Bau Um reservoirs ($P<0.05$). In general, phytoplankton biomass of Cau Moi Reservoir was more abundant than Bau Um Reservoir. The average phytoplankton biomass at Cau Moi was 1.53 gDW/m^3 or 3.37 gDW/m^2, while the average phytoplankton biomass at Bau Um was 0.73 gDW/m^3 or 2.05 gDW/m^2.

Table 1. Fluctuations of phytoplankton biomass at Cau Moi stocked reservoir.

Months	Phytoplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Jul	1.69 ± 0.04	1.57 ± 0.21	1.51 ± 0.12
Sep	1.45 ± 0.06	1.91 ± 0.26	1.29 ± 0.06
Nov	1.59 ± 0.19	1.63 ± 0.04	1.23 ± 0.12
Jan	1.43 ± 0.07	1.39 ± 0.06	1.17 ± 0.04
Mar	1.53 ± 0.07	1.47 ± 0.07	1.21 ± 0.08
May	1.91 ± 0.09	1.97 ± 0.09	1.59 ± 0.09

[ab] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Table 2. Fluctuations of phytoplankton biomass at Bau Um non-stocked reservoir.

Months	Phytoplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Aug	0.56 ± 0.11	0.48 ± 0.05	0.46 ± 0.12
Oct	0.32 ± 0.10	0.29 ± 0.04	0.24 ± 0.05
Dec	0.74 ± 0.05	0.82 ± 0.09	0.56 ± 0.04
Feb	0.79 ± 0.08	0.54 ± 0.07	0.48 ± 0.08
Apr	1.47 ± 0.13	1.35 ± 0.08	1.21 ± 0.05
Jun	0.98 ± 0.09	1.01 ± 0.07	0.91 ± 0.08

[ab] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Zooplankton biomass ranged from 0.05-0.83 g DW/m^3 during July-May at Cau Moi (Table 3), and from 0.11-1.27 g DW/m^3 during August-June at Bau Um (Table 4). Zooplankton biomass at the downstream stations were significant lower than the upstream and midstream stations of both Cau Moi and Bau Um reservoir ($P<0.05$). In general, zooplankton biomass of Bau Um was somewhat more abundant than that of Cau Moi. The average zooplankton biomass at Cau Moi was 0.31 gDW/m^3 or 1.86 gDW/m^2, while the average zooplankton biomass at Bau Um was 0.35 gDW/m^3 or 1.41 gDW/m^2.

Table 3. Fluctuations of zooplankton biomass at Cau Moi stocked reservoir.

Months	Zooplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Jul	0.22 ± 0.02	0.35 ± 0.03	0.2 ± 0.02
Sep	0.81 ± 0.04	0.83 ± 0.05	0.32 ± 0.03
Nov	0.50 ± 0.04	0.24 ± 0.02	0.26 ± 0.03
Jan	0.33 ± 0.04	0.14 ± 0.01	0.05 ± 0.01
Mar	0.24 ± 0.02	0.21 ± 0.02	0.17 ± 0.02
May	0.32 ± 0.03	0.24 ± 0.02	0.15 ± 0.01

[b] Values in the columns under the headers with different superscript letters were significantly different (P<0.05)

Table 4. Fluctuations of zooplankton biomass at Bau Um non-stocked reservoir.

Months	Zooplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Aug	0.25 ± 0.03	0.29 ± 0.03	0.20 ± 0.02
Oct	0.60 ± 0.07	0.33 ± 0.05	0.18 ± 0.03
Dec	1.27 ± 0.22	0.81 ± 0.13	0.68 ± 0.10
Feb	0.18 ± 0.02	0.22 ± 0.03	0.11 ± 0.01
Apr	0.22 ± 0.03	0.21 ± 0.03	0.20 ± 0.02
Jun	0.20 ± 0.02	0.20 ± 0.02	0.19 ± 0.02

[ab] Values in the columns under the headers with different superscript letters were significantly different (P<0.05)

Table 5. Fluctuations of benthos biomass at Cau Moi stocked reservoir.

Months	Benthos biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Jul	0.12	0.15	0.05
Sep	0.01	7.40	9.05
Nov	0.13	8.34	1.98
Jan	2.73	7.08	7.29
Mar	5.18	6.09	9.43
May	0.05	0.13	0.11

Benthos biomass ranged from 0.01-9.43 g DW/m^2 during July-May at Cau Moi Reservoir (Table 5), and from 0.08-0.64 g DW/m^2 during August-June at Bau Um Reservoir (Table 6). Benthic biomass was very poor at Bau Um (average was 0.41 gDW/m^2), while it was higher and exhibited more fluctuations at Cau Moi (averaging 3.63 gDW/m^2).

Table 6. Fluctuations of benthos biomass at Bau Um non-stocked reservoir.

Months	Benthos biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Aug	0.64	0.72	0.16
Oct	0.48	0.32	0.40
Dec	0.56	0.64	0.16
Feb	0.32	0.16	0.16
Apr	0.64	0.56	0.08
Jun	0.32	0.32	0.16

Table 7. Fluctuations of detritus biomass at Cau Moi stocked reservoir.

Months	Detritus biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Jul	469.9	496.8	546.8
Sep	307.7	406	251
Nov	352	627.6	458.7
Jan	5600.4	10245.8	6019.3
Mar	6014.4	7009.3	5184.4
May	5188.4	6791.4	8500.9

Table 8. Fluctuations of detritus biomass at Bau Um non-stocked reservoir.

Months	Detritus biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Aug	91.1	26.2	22.8
Oct	103.5	121.7	41.5
Dec	2931.6	3820.9	3670.9
Feb	4341.5	4122.6	2867.9
Apr	1393.2	3320.2	2906.3
Jun	4847.6	2360.4	1779.8

Detritus biomass ranged from 251-10,245 gDW/m^2 during July-May at Cau Moi Reservoir (Table 7), and ranged from 22.8-4,847 gDW/m^2 during August-June at Bau Um Reservoir (Table 8). In general, detritus biomass was more abundant at Cau Moi. The average detritus biomass at Cau Moi and Bau Um were 3581 gDW/m^2 and 2153 gDW/m^2, respectively.

Terrestrial vegetation biomass in the drawdown areas of the reservoirs (Table 9) was categorized into three groups according to the height of vegetation. The mean biomass of terrestrial plants for whole year was about 292 gDW/m^2 and 766 gDW/m^2 for Cau Moi and Bau Um reservoirs, respectively.

Table 9. Terrestrial vegetation biomass during July-August.

Reservoir	Vegetation height (cm)	The ratio (%)	Biomass (gDW/m^2)
Cau Moi	< 30	30	160.2
	30 - 70	55.	280.1
	> 70	15	603.3
	All size	100	292.6
Bau Um	< 30	10	326.7
	30 - 70	50	546.7
	> 70	40	1150.1
	All size	100	766.1

2. Fisheries at the 8 reservoirs

There were 63 fish species (Appendix 2) belonging to 23 families in the 8 reservoirs. Relative abundance by family was dominated by Cyprinidae (30%), and Bagridae (14%, Figure 1). Cyprinidae dominated distribution in all reservoirs with 19 species, then Bagridae with 9 species, Mastacembelidae with 4, the other families only had 1-3 species.

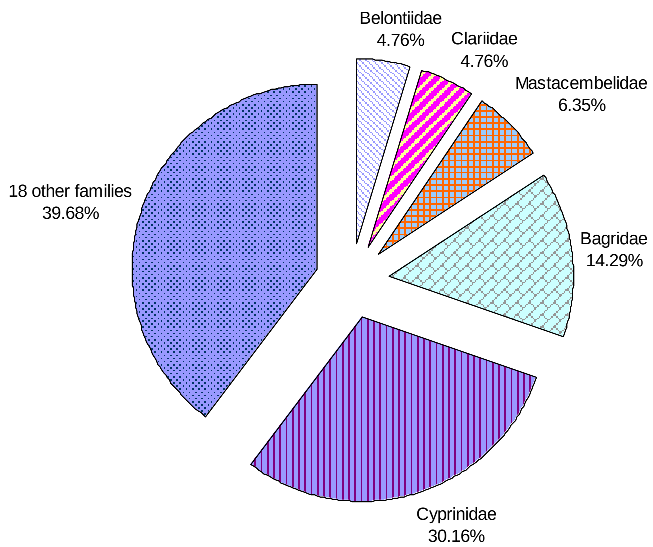

Figure 1. Fish family composition averaged for all 8 reservoirs.

Stocked reservoirs included Cau Moi (CM), Da Ton (DT), Gia Ui (GU), Dong xoai (DX), and Xa Cat (XC). Reservoirs without stocking included Bau Um (BU), Hung Phu (HP), Minh Hung, and Suoi Lai (SL). Dong Xoai had highest numbers of fish species (53 species belongs to 21 families) and accounted for 84% of all species observed, then Cau Moi with 45 species in 17 families, Gia Ui with 36 species in 19 families. Suoi Lai and Hung Phu had less species than the others; Suoi Lai with 25 species in 11 families and Hung Phu with 27 species in 15 families (Figure 2).

Fish in reservoirs without stocking included species from former rivers, escaped fish from culture ponds, and released fish from surrounding communities so the number of species and families in those reservoirs was lower than the stocked reservoirs. The difference depended mainly on the natural fish composition in the former rivers. Moreover, the number of species collected depended on the gears of people who fish in these reservoirs (Table 10).

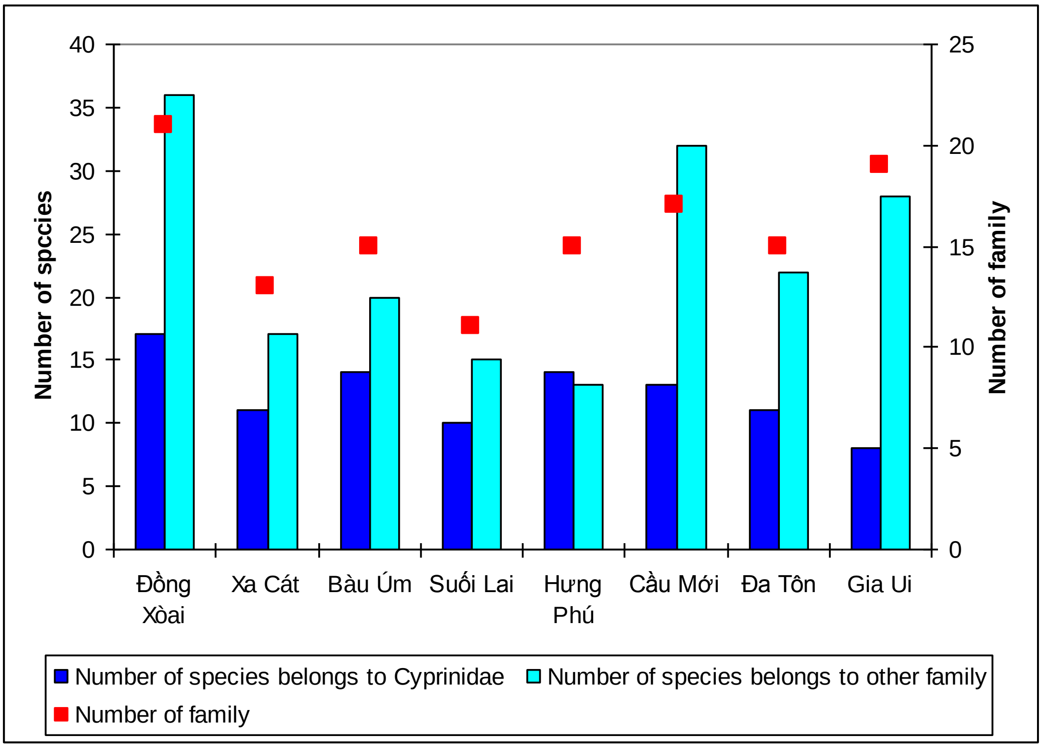

Figure 2. Number of fish species and families collected in each reservoir.

Table 10. Fishing gears used in the 8 reservoirs.

No.	Fishing gears	BU	SL	HP	DX	XC	CM	ĐT	GU
1	Hook	x	x	x	x	x	x	x	X
2	Line-hook				x	x		x	
3	Cast net	x	x		x	x			
4	Standing net	x			x				
5	Reef				x				
6	Bow net		x		x				
7	Prawn net	x	x	x		x			
8	Snake head net				x				
9	Trail net	x	x	x	x	x	x	x	X
10	Trammel net	x	x	x	x	x			
11	Floating lift net					x			
12	Improved bottom set net	x	x				x		X
13	Circle net						x	x	X
14	Improved set net							x	
Total		7	7	4	9	7	4	5	4

CPUE results of trail net and trammel net at different reservoirs (Tables 11 and 12) showed that CPUE at reservoirs without stocked fish was much lower than at reservoirs with stocked fish. This might be due to the number of fishermen as well as the production at each reservoir.

Table 11. CPUE (g/person/day) of trail nets at each reservoir.

Reservoir	CPUE (g/person/day)	
	Dry season	Rainy season
Bau Um	1.000 ± 816	2.785 ± 2.047
Suoi Lai	2.354 ± 1.078	3.758 ± 2.451
Hưng Phu	2.088 ± 712	2.488 ± 872
Đong Xoai	8.384 ± 7.594	5.277 ± 3.582
Xa Cat	4.744 ± 2.837	5.791 ± 2.232
Cau Moi	105.772 ± 39.837	45.541 ± 24.142
Đa Ton	75.754 ± 12.361	31.458 ± 9.467
Gia Ui	68.547 ± 38.245	20.457 ± 17.541

Table 12. CPUE (g/person/day) of trammel nets at each reservoir.

Reservoir	CPUE (g/person/day)	
	Dry season	Dry season
Bau Um	2.019±1.414	1.045±261
Suoi Lai	1.954±945	2.151±680
Hung Phu	2.105±814	2.287±744
Đong Xoai	5.345±2.361	6.670±3.300
Xa Cat	3.633±1.797	4.000±00

Mostly carp species were stocked in the reservoirs in 2010 (Table 13). There were 3 kinds of reservoir management; private, cooperative, and community group (Table 14). These kinds of management also affected the fish yields and fishing gears used.

Table 13. Number of fish stocked at 5 reservoirs.

Species	Cau Moi	Đa Ton	Gia Ui	Đong Xoai	Xa Cat
Silver carp	2,250 kg	1,840 kg	1,000 kg	55 kg	45 kg
Big head carp	2,250 kg			25 kg	15 kg
Indian carp	400 kg	200 kg			
Common carp	400 kg	1,400 kg	500 kg	30 kg	30 kg
Grass carp	400 kg			40 kg	30 kg
Silver barb			150 kg		
Total (kg)	**5,700**	**3,340**	**1,650**	**150**	**120**
Stocking density fish/m^2	0.4	0.2	0.1	0.007	0.062
Stocking density fish/ha	4,193.8	2,240.2	1,113.5	70.2	628.6

Table 14. Fisheries management at 5 reservoirs.

Reservoir	Management type	Established year	Re-established year
Cau Moi	Private	2008	
DaTon	Cooperative	2000	2010
Gia Ui	Cooperative	2001	2010
Xa Cat	Community group	2006	2010
Dong Xoai	Community group	2007	

Table 15. Fish yields at 5 reservoirs with stocking during 2010-2011.

Reservoir	Cultured fish yield kg/ha	% of total fish yield	Wild fish yield kg/ha	% of total fish yield	Productivity kg/ha
Cau Moi	640.9	95.7	29	4.3	670.0
Đa Ton	472.6	90.0	53	10.0	525.1
Gia Ui	422.5	93.0	32	7.0	454.3
Đong Xoai	81.7	71.8	32	28.2	113.7
Xa Cat	3 3.3	81.8	83	18.2	456.5

Fish yields at each reservoir were recorded (Table 15). The harvest from wild fish at reservoirs with stocking ranged from 29-83 kg/ha and was lower than harvest of wild fish at reservoirs without stocking (ranging from 36-89 kg/ha, Table 17). Stocked fish affected wild fish yield after reservoirs were established.

Table 16. Culturing efficiency (%) of stocked and wild fish in stocked reservoirs.

Reservoir	Area Ha	Stocked fish kg/ha	Yield kg/ha	Culturing efficiency %
Cau Moi	320	17.81	640.9	36.0
Đa Ton	328	10.18	472.6	46.4
Gia Ui	326	5.06	422.5	83.5
Đong Xoai	470	0.32	81.7	255.9
Xa Cat	42	2.86	373.3	130.7

Table 17. Yield of cultured and wild fish at reservoirs without stocking.

Reservoir	Yield of cultured fish kg/ha	% of total fish yield	Wild fish yield kg/ha	% of total fish yield
Bau Um	38	51.2	36	48.8
Hung Phu	110	55.3	89	44.7
Suoi Lai	87	66.6	44	33.4

Table 18. Aquatic species that disappeared (*) or had decreased yield (**) after reservoir establishment.

Local name	Scientific name	Cau moi	Đa Ton	Dong xoai	Xa Cat	Gia Ui
Cá chạch lấu	*Mastacembelus armatus*	**		**	**	
Cá ch nh	*Anguilla marmorata*	*		*		*
Cá đỏ mang	*Systomus orphoides*		**			**
Cá lìm kìm	*Hyporhamphus limbatus*			**		
Cá lăng nha	*Hemibagrus nemurus*	**	**	**	**	**
Cá lăng vàng	*Hemibagrus filamentus*				**	
Cá ngựa nam	*Hampala macrolepidota*	**		**	**	
Cá nhái	*Xenetodon cancila*			**	**	
Cá thát lát cư m	*Chitala ornata*			**		
Cá trê trắng	*Clarias batrachus*			**		
Cá Sặc rằn	*Trichogaster pectoralis*			**	**	
Tôm càng xanh	*Macrobrachium rosenbergii*	*		*		
		5	2	10	6	3

Higher rates of stocking did not necessarily result in a larger harvest of stocked fish in all reservoirs (Table 16). This will be discussed more detail when we analyze the relationship between the food web and fish yield.

The results from interview and group discussions with fishermen showed that eel and giant freshwater prawn disappeared after the reservoirs were established, while 4-8 other fish species (Table 18) had decreasing yield after reservoir establishment.

Table 19. Aquatic species with increasing yield after reservoir establishment.

No.	Local name	Scientific name	BU	CM	ĐT	DX	GU	HP	SL	XC
1	Cá bống tượng	*Oxyeleotris marmoratus*	x	x	x	x			x	
2	Cá chốt	*Mystus mysticetus*		x	x	x	x			
3	Cá lăng vàng	*Hemibagrus filamentus*				x				
4	Cá lóc đồng	*Channa striata*			x	x	x			
5	Cá mè vinh	*Barbodes gonionotus*			x					x
6	Cá ngựa nam	*Hampala macrolepidota*			x					
7	Cá rô biển	*Pristolepis fasciatus*	x			x			x	x
8	Cá rô đồng	*Anabas testudineus*		x		x	x			
9	Cá rô phi	*Oreochromis niloticus*	x	x	x	x	x	x	x	x
10	Cá đỏ mang	*Systomus orphoides*				x				
11	Cá sặc	*Trichogaster sp*		x		x	x			x
12	Cá sơn	*Parambassis sp.*		x		x			x	
13	Cá trê vàng	*Clarias macrocephalus*	x		x	x		x		x
14	Cá tr n	*Kryptopterus moorei*			x					
15	Lòng tong	*Rasbora sp.*		x		x	x	x	x	x
16	T p	*Macrobrachium sp.*	x	x	x	x	x	x	x	x

Depending on the origin of fish composition and fisheries management type, some aquatic species in the 8 reservoirs had increasing yield after the reservoir was established. Most of reservoirs with stocked fish had more fish species with increasing yields after reservoir establishment (Table 19).

3. Fish and food chains

Based on feeding habits and economic value, the fish found in Cau Moi and Bau Um reservoirs could be categorized as economically important, predatory, or small low-value fish. The diet matrix in Table 20 was obtained from results of stomach content analyses available in the literature.

The economically important fish were all high-value non-predatory fishes that grew quickly and reached large size. The major cultured and wild fish species included common carp, bighead carp, silver carp, grass carp, tilapia, mrigal, and rohu. The predatory fishes also grew quickly and reached a large size. They have good quality flesh and a high economic value. The main predatory fishes include Chevron snakehead, giant snakehead, *Wallago attu*, *Mystus wycki*, marbled sleeper, and bronze featherback. The small, low-value fishes grew slowly, remained small, and were generally of low economic value. They may compete for food with the economically important fish. The main low-value fishes in coves are: *Dangila spilopleura*, *Mystus spp*., *Osteochilus hasselti*, *Chanda gymnocephala*, and river sprat.

4. Trophic model at Cau Moi Reservoir

The input parameters of Ecopath modeling are given in Table 21 for the study period. The ecotrophic efficiency (EE) of cultured fish and carnivorous fish was set at 0.99, indicating total harvest at late stages of the culture period. The EE values for small wild fish, benthos, zooplankton, phytoplankton, vegetation, and detritus were set at 0.919, 0.325, 0.719, 0.738, 0.026, and 0.320, respectively (Table

21). There were very high EE values for small wild fish, phytoplankton, and zooplankton, ranging from 0.719 to 0.919.

A quantitative representation of the trophic interaction at Cau Moi Reservoir for the entire culture period is presented in Figure 3. Discrete trophic levels of the system are shown in Table 22. The average trophic levels of bighead carp, silver carp, mrigal, common carp, grass carp, tilapia, carnivorous fish, and small wild fish were 2.25, 2.0, 2.0, 2.58, 2.0, 2.11, 3.13, and 2.26, respectively. The bulk of the flows were at trophic level I and II, with total flow of 1829.9 and 1131.3 g DW/m^2, respectively. The flows at trophic level III and IV were 85.6, and 4.5 g DW/m^2, respectively.

Table 20. Diet composition of various species in Truong Dang Cove (% by weight).

Predator	Prey						Sources
	8	9	10	11	12	13	
1. Bighead carp	-	-	24	7	-	69	(a)
2. Silver carp	-	-	-	84	-	16	(a)
3. Mrigal	-	-	-	30	20	50	(b)
4. Common carp	-	50	-	-	-	50	(b), (c)
5. Grass carp	-	-	-	-	85	15	(d)
6. Tilapia	-	-	10	25	10	55	(b)
7. Carnivorous fish	85	5	-	-	-	10	(e), (f)
8. Small wild fish	-	-	25	40	-	35	(e), (f)
9. Benthos	-	5	10	20	-	65	(g), (h)
10. Zooplankton	-	-	5	95	-	-	(i)
11. Phytoplankton	-	-	-	-	-	-	
12. Vegetation	-	-	-	-	-	-	
13. Detritus	-	-	-	-	-	-	

Sources: (a) Cremer and Smitherman (1980); (b) Jørgensen (1979); (c) Specziár et al. (1997); (d) Colle et al. (1978); (e) Luong (2004); (f) Rainboth (1996); (g) Moreau et al. (1993); (h) Leveque et al. (1983); (i) Moriarty et al. (1973).

Table 21. Input and Ecopath estimated (values in parentheses) parameters for the study period at Cau Moi Reservoir.

Group	Biomass gDW/m^2	P/B (/crop)	Q/B (/crop)	P/Q (/crop)	EE (/crop)	Trophic level
Bighead carp	2.94	1.79	12.60	(0.142)	0.99	(2.25)
Silver carp	3.01	1.75	18.38	(0.95)	0.99	(2.00)
Mrigal	0.39	1.75	12.00	(0.46)	0.99	(2.00)
Common carp	0.21	1.79	11.17	(0.60)	0.99	(2.58)
Grass carp	0.34	1.65	27.12	(0.61)	0.99	(2.00)
Tilapia	0.17	1.70	15.30	(0.11)	0.99	(2.11)
Carnivorous fish	3.04	1.01	6.70	(0.15)	0.99	(3.13)
Small wild fish	12.16	1.55	15.50	(0.1)	(0.919)	(2.26)
Benthos	3.63	8.05	40.25	(0.2)	(0.325)	(2.16)
Zooplankton	1.86	81.32	406.6	(0.2)	(0.719)	(2.05)
Phytoplankton	3.37	351.67	-	-	(0.738)	(1.00)
Vegetation	292.6	1.19	-	-	(0.026)	(1.00)
Detritus	3581.7	-	-	-	(0.320)	(1.00)

P/B and Q/B rations are from Luong (2004)

Table 22. Trophic transformation matrix for the study period at Cau Moi Reservoir presenting trophic flows (gDW/m^2/crop) for each group at discrete trophic levels.

Group	Trophic level	Absolute flows by trophic level			
		I	II	III	IV
Bighead carp	2.25	-	28.2	8.9	-
Silver carp	2.00	-	55.3	-	-
Mrigal	2.00	-	4.7	-	-
Common carp	2.58	-	1.2	1.0	0.1
Grass carp	2.00	-	9.2	-	-
Tilapia	2.11	-	2.3	0.3	-
Carnivorous fish	3.13	-	2.0	13.9	4.4
Small wild fish	2.26	-	141.4	47.1	-
Benthos	2.16	-	130.7	15.4	-
Zooplankton	2.05	-	756.3	-	-
Phytoplankton	1.00	1185.1	-	-	-
Vegetation	1.00	9.0	-	-	-
Detritus	1.00	635.8	-	-	-
Total	-	1829.9	1131.3	85.6	4.5

5. Predicted ecological efficiencies from different simulated management scenarios using Ecopath model

Using Ecopath modeling, various options for manipulation of Cau Moi reservoir's food web are presented in Table 23. Manipulation focused first on the objective to reduce ecological efficiencies (EE) of small wild fish by increasing small wild fish biomass 30%, resulting in the small wild fish's EE value changing to 0.706.

In step II, biomass of herbivorous and small wild fish were increased by 50%, resulting in EE values of 0.919, 0.874, and 0.769 for small wild fish, zooplankton, and phytoplankton, respectively. In step III, biomass of small wild fish was increased by 100%, resulting in EE for zooplankton over 1, indicating not enough zooplankton food to support the system. In step IV, biomass of silver carp was increased by 400% to utilize phytoplankton in the system, changing the EE for phytoplankton to 0.894.

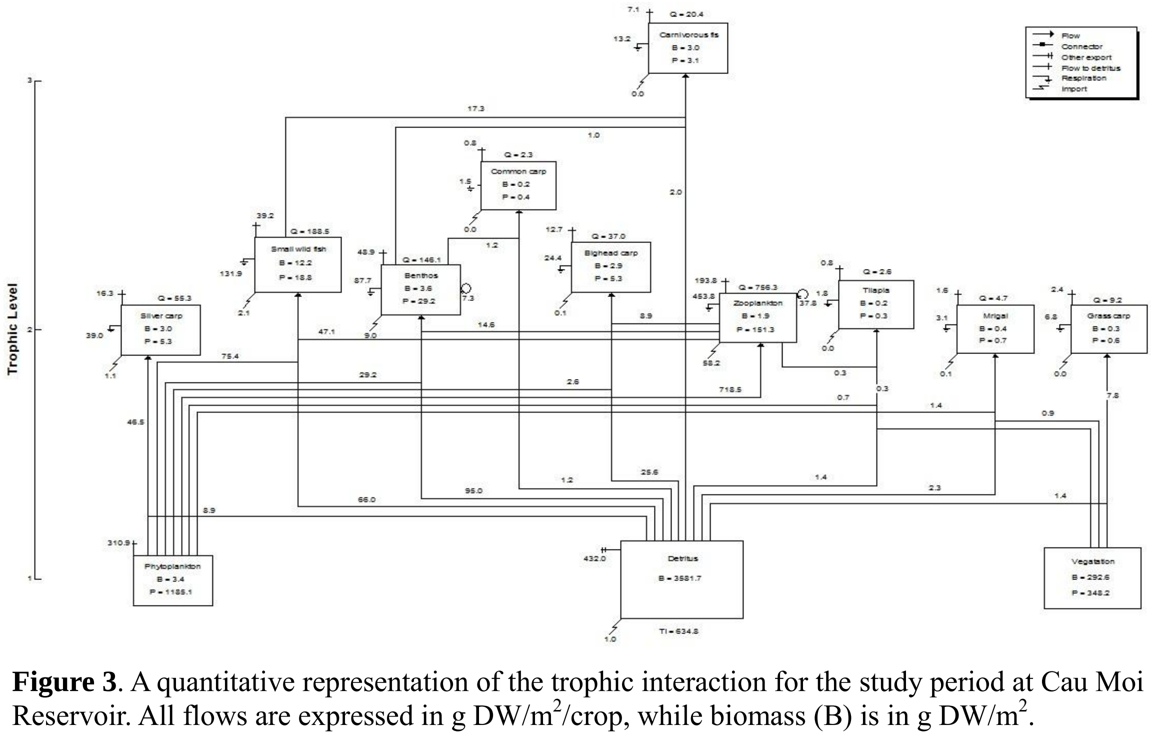

Figure 3. A quantitative representation of the trophic interaction for the study period at Cau Moi Reservoir. All flows are expressed in g DW/m^2/crop, while biomass (B) is in g DW/m^2.

Table 23. Predicted ecological efficiencies (EE) from different simulated management scenarios using Ecopath model.

Steps	Objectives	Adjustments	Affected factors	Results
I	To reduce EE of small wild fish	B = 15.81 gDW/m^2 for small wild fish (30% increasing)	EE = 0.812 for zooplankton and 0.757 for phytoplankton	EE = 0.706 for small wild fish
II	To increase biomass of carnivorous and small wild fish	B = 4.56 and 18.24 gDW/m^2 for carnivorous and small wild fish, respectively (50% increasing)	EE = 0.874 for zooplankton and 0.769 for phytoplankton	EE = 0.919 for small wild fish
III	To increase biomass of small wild fish	B = 24.32 gDW/m^2 for small wild fish (100% increasing)	EE = 0.801 for phytoplankton	EE = 1.03 for zooplankton
IV	To increase biomass of silver carp	B = 15.05 gDW/m^2 for silver carp (400% increasing)	EE = 0.499 for detritus	EE = 0.894 for phytoplankton

Table 24. Input and estimated parameters for the yearly period at Bau Um Reservoir (as in Table 21).

Group	Biomass gDW/m^2	P/B (/crop)	Q/B (/crop)	P/Q (/crop)	EE (/crop)	Trophic level
Bighead carp	2.0	1.79	12.60	(0.142)	0.99	(2.25)
Silver carp	1.0	1.75	18.38	(0.95)	0.99	(2.00)
Common carp	0.4	1.79	11.17	(0.60)	0.99	(2.58)
Grass carp	10.0	1.65	27.12	(0.61)	0.99	(2.00)
Carnivorous fish	2.4	1.01	6.70	(0.15)	0.99	(3.13)
Small wild fish	10.0	1.55	15.50	(0.1)	(0.882)	(2.26)
Benthos	0.41	8.05	40.25	(0.2)	(0.927)	(2.16)
Zooplankton	1.41	81.32	406.6	(0.2)	(0.655)	(2.05)
Phytoplankton	2.05	351.67	-	-	(0.870)	(1.00)
Vegetation	766.1	1.19	-	-	(0.253)	(1.00)
Detritus	2153.9	-	-	-	(0.124)	(1.00)

6. Trophic model for the yearly period at Bau Um Reservoir

The input parameters for Ecopath modeling are given in Table 24 for the study year in Bau Um Reservoir. The ecotrophic efficiency of harvested fish was set at 0.99, indicating total harvest at the late stage of the culture period. The EE values for small wild fish, benthos, zooplankton, phytoplankton, vegetation, and detritus were 0.882, 0.927, 0.655, 0.870, 0.253, and 0.124, respectively (Table 24). There were very high EE values for benthos, phytoplankton, and small wild fish, ranging from 0.870 to 0.927.

A quantitative representation of the trophic interaction at Bau Um Reservoir for the study year is presented in Figure 4. The average trophic levels of bighead carp, silver carp, common carp, grass carp, carnivorous fish, and small wild fish were 2.25, 2.0, 2.58, 2.0, 3.13, and 2.26, respectively. In the system, the bulk of flows were at trophic level I and II, with total flow of 2690 and 1017 gDW/m^2, respectively. The flows at trophic level III and IV were only 58.8 and 3.7 gDW/m^2, respectively.

Table 25. Trophic transformation matrix for the yearly period at Bau Um Reservoir presenting trophic flows (gDW/m^2/crop) for each group in the system on discrete trophic levels.

Groups	Trophic level	Absolute flows by trophic level			
		I	II	III	IV
Bighead carp	2.25	-	19.2	6.1	-
Silver carp	2.00	-	18.4	-	-
Common carp	2.58	-	2.2	2.0	0.2
Grass carp	2.00	-	271.2	-	-
Carnivorous fish	3.13	-	2.4	10.3	3.4
Small wild fish	2.26	-	116.3	38.8	-
Benthos	2.16	-	14.8	1.7	-
Zooplankton	2.05	-	573.3	-	-
Phytoplankton	1.00	720.9	-	-	-
Vegetation	1.00	911.7	-	-	-
Detritus	1.00	1057.5	-	-	-
Total	-	2690.1	1017.7	58.8	3.7

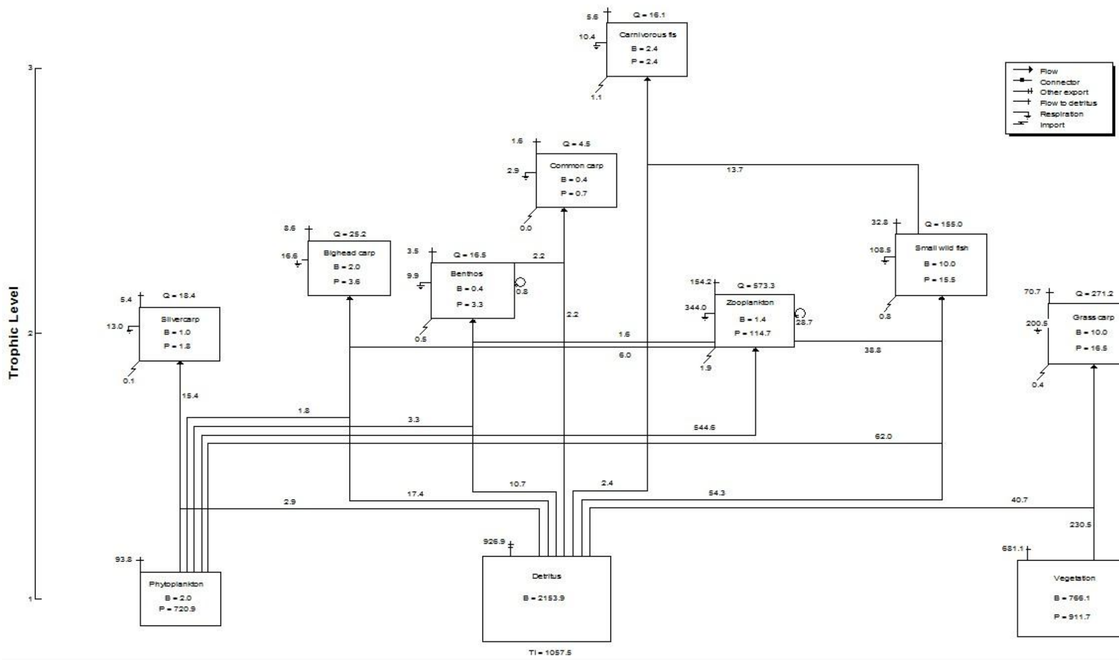

Figure 4. A quantitative representation of the trophic interaction for the yearly period at Bau Um non-stock reservoir. All flows are expressed in g DW/m^2/crop, while biomass (B) is in g DW/m^2.

DISCUSSION

The reservoir without stocked fish had higher transparency and lower toxic substance concentrations than the reservoir with stocking. However, water quality in both reservoirs was suitable for fish survival. Water quality in Cau Moi Reservoir, with stocked fish, still met the quality for irrigation (standard of Vietnamese Ministry of Environment and Natural Resources, 2005). Water quality in Bau Um reservoir was even cleaner water but had poor natural food.

Huang D. and et al. (2001), Li Sifa (2001) and Tuantong Jutagate (2009) reported that dam construction affected on the indeginous fish composition in reservoirs, especially fish has migration for spawning, prey for food or suitable habitat for each life stage. Those species tend to be excluded their life environment. It is obviuos that giant fresh water prawn (*Macrobrachium rosenbergii*) and fresh water eel (*Anguilla marmorata*) disappear in most of investigated reservoirs, or *Systomus orphoides* never present in Da Ton reservoir after it is established. Moreover, the wide fluctuation of water level in reservoirs also causing the lost of spawning ground of some fish species that laying sticky eggs. In the year of 2010, the low precipitation and the low water level in reservoirs due to supplying more water for crop lead the spawning grown drying. Therefore, the yield of some species decrease in the next year. However, the storing water in reservoirs also stimulate the growing and propagation of some indeginous and exotic species inside theirs such as marble goby, silver barb, tilapia, snake head, etc. Beam (1983) and De Silva (1985) also reported that the periodic increasing water level created the active affect on the increasing yield of some fish species in reservoirs.

The transparency and low nutrient in Bau Um reservoir lead to less phytoplankton biomass comparing to the richer nutrient in Cau Moi reservoir with abundant plankton. These results explain the yield of herbivorous fish in Bau Um reservoir is lower than in Cau Moi reservoir although the fishing in those reservoirs is different.

According to Russell-Hunter (1970), fluctuations in the aquatic food web are controlled by the interaction of several factors, which are usually divided into three groups: (1) physical factors such as light intensity, temperature, mixing and turbulence caused by wind action; (2) content of nutrients in the water body; and (3) interaction of organisms present in the aquatic community which may promote or hamper production of certain species. In this study, fluctuations of the food web in studied reservoirs were affected greatly by wide fluctuation of water level and severe drawdown.

Fluctuations by phytoplankton in reservoirs are one of the most interesting areas of study to aquatic biologists. Algae can be utilized indirectly through secondary trophic levels (zooplankton, benthos, invertebrates, etc.) or directly through grazing by fish. Average plankton biomass (0.73-1.53 g DW/m^3) in the reservoirs measured in this study was higher than the average value (0.3 g DW/m^3) in lakes and reservoirs in South Vietnam reported by Shirota (1966). Phytoplankton biomass of Cau Moi stocked reservoir was more abundant than that of Bau Um non-stocked reservoir, indicating better culture potential for herbivorous fish at Cau Moi Reservoir.

The development of zooplankton in reservoirs depends on phytoplankton biomass and environmental factors such as location and physicochemical characteristics (Bhukaswan, 1973). At Cau Moi stocked reservoir, phytoplankton and zooplankton biomass were 1.53 and 0.31 gDW/m^3, respectively. At Bau Um non-stocked reservoir, phytoplankton and zooplankton biomass were 0.73 and 0.35 gDW/m^3, respectively. Bau Um reservoir may have more favorable environment conditions for zooplankton development. In the present study, the fluctuations of zooplankton biomass were very large, ranging from 0.05-0.83 gDW/m^3 during July-May at Cau Moi, and from 0.11-1.27 gDW/m^3 during August-June at Bau Um, indicating an unstable food source of zooplankton.

Compared with plankton, development of benthos in reservoirs is a long process that varies depending on bottom conditions, water level fluctuations, water depth, siltation, hypolimnetic oxygen deficiency, hydrostatic pressure, light intensity, and other impoundment associated conditions (Isom, 1971). Grimas (1961) stated that water level fluctuations caused a quantitative reduction of the bottom fauna up to 70% in the drawdown zone of Swedish reservoirs, and 25% for the remaining area. In the present study, there were strong fluctuations in benthic biomass in both reservoirs, indicating strong effects of water level fluctuations on benthic fauna. Benthos therefore became one of limited food sources in these reservoirs.

Terrestrial vegetation that grows in the drawdown area during dry season is another unique feature of reservoirs. The terrestrial vegetation becomes sources of food and nutrients for aquatic ecosystems after inundation. Only a small part of flooded and surrounding-shore grasses were consumed directly by grass carp, and most terrestrial plants were decomposed to detritus after flooding. Terrestrial vegetation plays an important role in releasing nutrients through decomposition for natural food production in coves. Although there was no measurement of nutrient releases from terrestrial plant decomposition, such results directly affect the development of phytoplankton biomass in the system. Abundant terrestrial plant biomass resulted in good development of phytoplankton biomass in studied reservoirs.

To assess the role of natural food sources in our reservoirs, the Ecopath model combined an approach for estimating biomass and food consumption of various species in the aquatic ecosystem. In this study, trophic models for the system were constructed following a "bottom up" approach by estimating most of the actions and processes involving all individuals in the ecosystem. The modeling procedure therefore reduced assumptions. As the main objective for food web manipulation is to assess and manage trophic chains within reasonable EE values, steady-state models can be used to describe ecosystems (Christensen and Pauly, 1993).

During the entire culture period at Cau Moi stocked reservoir, EE values estimated by Ecopath for detritus, terrestrial vegetation, and benthos were very low, ranging from 0.026 to 0.325. The low EE values implied that most production of detritus, terrestrial vegetation, and benthos was not consumed by any trophic group in the system. This suggests that there is still room for additional stocking of fish species to utilize such foods.
The EE values of phytoplankton and zooplankton (0.719–0.738) at Cau Moi stocked reservoir indicated that both phytoplankton and zooplankton may still be available for additional stocking of herbivorous fish. The very high EE values for small wild fish (0.919) at Cau Moi stocked reservoir indicated that prey fish were fully utilized by higher trophic levels. However, because there was no harvest data for small wild fish, their biomass could be more abundant at Cau Moi than we estimated.

Trophic levels for all components were similar in the models for stocked and non-stocked reservoirs, in which the trophic levels were highest for carnivorous fish (3.13). There were seven species and groups of species occupying trophic levels from 2 to 2.58, including bighead carp, silver carp, mrigal, common carp, grass carp, tilapia, and small wild fish. Such a high quantity of species in this trophic group resulted in the bulk of the trophic flows at levels I and II, and increased potential for food competition. Therefore, appropriate manipulation strategies should be implemented to reduce the number of species at the same trophic level. The trophic flows, however, were very low at trophic levels III and IV, mostly from carnivorous fish. To increase the flows in these higher trophic levels, utilization of small wild fish by predatory fish should be enhanced.

Manipulation of food webs at Cau Moi stocked reservoir was done in three directions: (1) to utilize the small wild fish source; (2) to enhance stocking of carnivorous fish; and (3) to utilize phytoplankton as a food source. According to Christensen et al. (2000), EE values of the food web components can be rationalized by adjustments in fish stocking densities. In this study, as wild fish consumption by carnivorous fish was limited, step I of manipulation was to increase biomass of small wild fish by 30%, which the models showed had more potential to enhance both carnivorous and small wild fish biomass. In step II, biomass of herbivorous and small wild fish was increased by 50%, and the balance of the system indicated this could be applied to manage fish stocked. However, when biomass of small wild fish was increased by 100%, the EE value of zooplankton indicated that plankton abundance was the limiting factor for the system. Another management solution would be to increase biomass of silver carp to utilize the phytoplankton food source.

While the Cau Moi stocked-reservoir was managed well with good harvest data, the Bau Um non-stocked reservoir did not have good harvest information. Based on the balance of all trophic flows in the models, we evaluated the manipulation process for Bau Um non-stocked reservoir in order to estimate a suitable stocking strategy. For Bau Um non-stocked reservoir, stocked fish biomass was set to fit the EE values of natural food sources in the reservoir. In this reservoir, several factors were important: (1) benthos abundance was very low, reducing common carp stocking; (2) abundance of terrestrial vegetation could allow more grass carp to be stocked; (3) suitable biomass of carnivorous and small wild fish was present; and (4) there was still an abundant zooplankton food source but the limitation of phytoplankton may occur in the future.

ANTICIPATED BENEFITS

The major impact of this study will allow managing the stocking strategy of indigenous and exotic species into small irrigation reservoirs. Specific information on the impacts of cultured fish species on fisheries and natural food resources will allow governmental agencies and local communities to establish policies, plans and mechanisms for stocking of cultured fish species.

Specifically, this study estimated the impact of stocking cultured fish species on fish production in small irrigation reservoirs. The studied food webs in reservoirs with and without cultured fish species indicated diet overlap and potential competition between some cultured and wild species. Additionally, the management of water in reservoir for irrigation and other uses affect on the inundated spawning ground of some fish species and the abundant of plankton – natural food for herbivorous indeginoous or exotic fish in reservoirs. These reason create the concerns of local management agencies for purpose of fish culture in small and medium reservoirs.

We were able to estimate environmental carrying capacity for fish stocking in each reservoir. Moreover, physical-chemical and biological parameters provide useful information on the impact of aquaculture activities on the environment, especially in waters used for irrigation purposes.

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Appendix 1

WATER QUALITY AT BAU UM AND CAU MOI RESERVOIR

Cau Moi reservoir

Table 1. Temperature (^{0}C) at different sampling points.

Sampling points	Temperature (^{0}C)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	29.0	29.0	29.0	29.6	
Midstream	29.0	29.0	29.0	29.8	
Downstream	29.0	29.0	29.0	29.8	
Average	$29.0^a \pm 0.0$	$29.0^a \pm 0.0$	$29.0^a \pm 0.0$	$29.7^b \pm 0.1$	29.2 ± 0.4

Table 2. Transparency (cm) at different sampling points.

Sampling points	Transparency (cm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	75.0	75.0	85.0	80.0	
Midstream	75.0	80.0	80.0	85.0	
Downstream	80.0	80.0	85.0	80.0	
Average	$76.7^a \pm 2.9$	$78.3^a \pm 2.9$	$83.3^a \pm 2.9$	$81.7^a \pm 2.9$	80.0 ± 3.0

Table 3. pH at different sampling points.

Sampling points	pH				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	7.5	7.5	7.2	7.4	
Midstream	7.7	7.3	7.4	7.5	
Downstream	7.7	7.3	7.2	7.4	
Average	$7.6^b \pm 0.1$	$7.4^a \pm 0.1$	$7.3^{ab} \pm 0.1$	$7.4^{ab} \pm 0.1$	7.4 ± 0.2

Table 4. Total alkalinity ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total alkalinity ($mgCaCO_3/l$)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$51.67^a_x \pm 2.89$	$51.67^a_x \pm 2.51$	$59.33^b_x \pm 1.15$	$57.67^b_x \pm 0.58$	
Midstream	$50.00^a_x \pm 0.00$	$53.00^a_x \pm 1.00$	$51.67^a_y \pm 1.53$	$57.00^b_x \pm 1.73$	
Downstream	$46.67^a_x \pm 3.21$	$52.67^a_x \pm 4.01$	$63.67^b_z \pm 1.53$	$63.33^b_z \pm 1.53$	
Average	$49.45^a \pm 2.55$	$52.45^a \pm 0.69$	$58.22^a \pm 6.08$	$58.22^a \pm 3.48$	54.59 ± 4.37

Table 5. Dissolved oxygen (mgO_2/l) at different sampling points.

Sampling points	Dissolved oxygen (mgO_2/l)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	4.9	4.4	5.1	4.4	
Midstream	5.0	4.4	5.5	4.5	
Downstream	5.2	4.6	5.5	4.5	
Average	$5.0^{ab} \pm 0.2$	$4.5^{c} \pm 0.1$	$5.4^{b} \pm 0.2$	$4.5^{ac} \pm 0.3$	4.8 ± 0.4

Table 6. Total ammonia concentration (ppm) at different sampling points.

Sampling points	Total ammonia concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.062^{a}\pm0.033$	$0.161^{a}\pm0.097$	$0.482^{b}\pm0.031$	$0.074^{a}\pm0.018$
Midstream	$0.076^{a}\pm0.008$	$0.225^{a}\pm0.033$	$0.516^{b}\pm0.041$	$0.037^{a}\pm0.006$
Downstream	$0.050^{a}\pm0.023$	$0.742^{a}\pm1.031$	$0.519^{a}\pm0.030$	$0.076^{a}\pm0.036$

Table 7. Nitrite concentration (ppm) at different sampling points.

Sampling points	Nitrite concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$
Midstream	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.003^{b}\pm0.000$	$0.002^{a}\pm0.000$
Downstream	$0.005^{a}\pm0.000$	$0.005^{a}\pm0.000$	$0.002^{b}\pm0.000$	$0.005^{a}\pm0.000$

Table 8. Total phosphorus concentration (ppm) at different sampling points.

Sampling points	Total phosphorus concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.024^{a}\pm0.011$	$0.008^{a}\pm0.002$	$0.034^{a}\pm0.005$	$0.212^{a}\pm0.259$
Midstream	$0.013^{a}\pm0.011$	$0.009^{a}\pm0.004$	$0.031^{a}\pm0.008$	$0.113^{b}\pm0.051$
Downstream	$0.017^{a}\pm0.006$	$0.013^{a}\pm0.002$	$0.028^{a}\pm0.006$	$0.070^{b}\pm0.029$

Bau Um reservoir

Table 9. Temperature (^0C) at different sampling points.

Sampling points	Temperature (^0C)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	28.5	28.0	29.0	28.5	
Midstream	28.0	28.0	29.0	28.5	
Downstream	28.0	28.0	29.0	29.0	
Average	$28.3^{ac} \pm 0.3$	$28.0^{c} \pm 0.0$	$29.0^{b} \pm 0.0$	$28.8^{ab} \pm 0.3$	28.5 ± 0.5

Table 10. Transparency (cm) at different sampling points.

Sampling points	Transparency (cm)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	90	100	95	110	
Midstream	90	95	95	110	
Downstream	90	95	95	110	
Average	$90.0^{a}\pm0.0$	$96.7^{b}\pm2.9$	$95.0^{b}\pm0.0$	$110.0^{c}\pm0.0$	97.9 ± 8.5

Table 11. pH at different sampling points.

Sampling points	pH				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	6.90	6.80	6.80	7.16	
Midstream	6.80	6.80	6.80	7.12	
Downstream	6.90	6.90	6.90	7.08	
Average	$6.86^{a}\pm0.05$	$6.83^{a}\pm0.05$	$6.83^{a}\pm0.05$	$7.12^{b}\pm0.04$	$6.91^{a}\pm0.14$

Table 12. Total alkalinity ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total alkalinity ($mgCaCO_3/l$)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$19.33^{a}\pm0.58$	$21.67^{b}\pm0.58$	$29.00^{c}\pm1.00$	$30.67^{c}\pm1.56$
Midstream	$21.00^{a}\pm1.00$	$22.00^{a}\pm1.73$	$29.33^{b}\pm0.58$	$31.00^{b}\pm1.00$
Downstream	$26.67^{a}\pm1.53$	$20.00^{b}\pm1.00$	$28.67^{a}\pm0.58$	$31.67^{c}\pm0.58$

Table 13. Total hardness ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total hardness ($mgCaCO_3/l$)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	-	-	$27.36^{a}_{x}\pm1.16$	$35.70^{b}_{x}\pm0.58$	
Midstream	-	-	$26.69^{a}_{x}\pm1.53$	$34.70^{b}_{x}\pm1.16$	
Downstream	-	-	$29.03^{a}_{x}\pm0.00$	$41.04^{b}_{y}\pm1.73$	
Average	-	-	$27.70^{a}\pm1.21$	$37.15^{b}\pm3.17$	32.42 ± 6.68

Table 14. Dissolved oxygen (mgO_2/l) at different sampling points.

Sampling points	Dissolved oxygen (mgO_2/l)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	4.2	4.6	4.4	4.3	
Midstream	4.4	5	4.5	3.9	
Downstream	4.4	5.2	4.3	3.9	
Average	$4.3^{ab}\pm0.1$	$4.9^{a}\pm0.3$	$4.4^{ab}\pm0.1$	$4.0^{b}\pm0.2$	4.4 ± 0.4

Table 15. Total ammonia concentration (ppm) at different sampling points.

Sampling points	Total ammonia concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.148^{a}_{x} \pm 0.077$	$0.259^{a}_{x} \pm 0.043$	$0.014^{b}_{x} \pm 0.015$	$0.237^{a}_{x} \pm 0.019$	
Midstream	$0.000^{a}_{y} \pm 0.000$	$0.227^{b}_{x} \pm 0.035$	$0.000^{a}_{x} \pm 0.000$	$0.268^{b}_{x} \pm 0.012$	
Downstream	$0.148^{c}_{x} \pm 0.024$	$0.091^{ac}_{y} \pm 0.021$	$0.000^{a}_{x} \pm 0.000$	$0.270^{b}_{x} \pm 0.079$	
Average	$0.099^{ab} \pm 0.085$	$0.192^{a} \pm 0.089$	$0.005^{b} \pm 0.008$	$0.258^{a} \pm 0.019$	0.139 ± 0.11

Table 16. Nitrite concentration (ppm) at different sampling points.

Sampling points	Nitrite concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.001^{ab}_{x} \pm 0.001$	$0.003^{bc}_{x} \pm 0.001$	$0.000^{a} \pm 0.000$	$0.003^{c}_{y} \pm 0.001$	
Midstream	$0.002^{bc}_{x} \pm 0.001$	$0.002^{b}_{x} \pm 0.001$	$0.000^{ac} \pm 0.000$	$0.001^{a}_{x} \pm 0.001$	
Downstream	$0.001^{a}_{x} \pm 0.000$	$0.001^{a}_{y} \pm 0.000$	$0.000^{b} \pm 0.000$	$0.001^{ab}_{x} \pm 0.001$	
Average	$0.0013^{a} \pm 0.001$	$0.002^{a} \pm 0.001$	$0.000^{a} \pm 0.000$	$0.0017^{a} \pm 0.001$	0.0013 ± 0.0009

Table 17. Total phosphorus concentration (ppm) at different sampling points.

Sampling points	Total phosphorus concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.024^{a}_{y} \pm 0.001$	$0.038^{b}_{x} \pm 0.003$	$0.025^{a}_{x} \pm 0.004$	$0.049^{c}_{y} \pm 0.006$	
Midstream	$0.020^{b}_{xy} \pm 0.002$	$0.036^{a}_{x} \pm 0.005$	$0.030^{ab}_{x} \pm 0.006$	$0.024^{ab}_{x} \pm 0.009$	
Downstream	$0.018^{c}_{x} \pm 0.001$	$0.059^{a}_{y} \pm 0.006$	$0.036^{b}_{x} \pm 0.006$	$0.027^{bc}_{x} \pm 0.007$	
Average	$0.021^{a} \pm 0.003$	$0.044^{a} \pm 0.013$	$0.030^{a} \pm 0.006$	$0.033^{a} \pm 0.014$	0.032 ± 0.010

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
1	*Anabantidae*	*Anabas testudineus (Bloch.1792)*	Cá rô đồng	x	x	x	x	x	x	x	x
2	*Anguillidae*	*Anguilla marmorata (Quoy. 1824)*	Cá chình hoa							x	
3	*Bagridae*	*Bagriichthys obscurus (Bleeker. 1854)*	Cá lăng tối/chuột					x			
4	*Bagridae*	*Leiocassis siamensis (Regan.1913)*	Cá chốt bông	x				x	x		
5	*Bagridae*	*Mystus albolineatus (Roberts.1994)*	Cá chốt giấy	x				x			
6	*Bagridae*	*Mystus mysticetus (Roberts.1992)*	Cá chốt sọc					x	x		
7	*Bagridae*	*Mystus rhegma (Fowler.1935)*	Cá chốt vạch					x			
8	*Bagridae*	*Mystus singaringan (Bleeker. 1846)*	Cá chốt ngựa singa					x			
9	*Bagridae*	*Hemibagrus filamentus (Fang and Chaux. 1949)*	Cá lăng vàng	x				x		x	
10	*Bagridae*	*Hemibagrus wyckioides (Fang and Chaux. 1949)*	Cá lăng đỏ	x							
11	*Bagridae*	*Hemibagrus nemurus (Valenciennes. 1839)*	Cá lăng nha	x		x					
12	*Balitoridae*	*Nemacheilus platiceps (Kottelat. 1990)*	Cá chạch suối platy	x							
13	*Balitoridae*	*Nemacheilus masyae (Smith. 1933)*	Cá chạch suối nam	x							
14	*Belonidae*	*Xenetodon cancila (Hamilton. 1822)*	Cá nhái	x	x						
15	*Belontiidae*	*Trichopsis vittata (Cuvier. 1831)*	Cá bẫy trầu	x	x	x	x	x	x	x	X
16	*Chandidae*	*Parambassis apogonoides (Bleeker. 1851)*	Cá sơn giả	x			x	x	x	x	X
17	*Chandidae*	*Parambassis wolffii (Bleeker. 1851)*	Cá sơn bầu	x			x	x	x	x	X
18	*Channidae*	*Channa striata (Bloch.1795)*	Cá lóc đồng	x	x	x	x	x	x	x	X
19	*Channidae*	*Channa gachua (Hamilton. 1822)*	Cá trào chó		x	x					
20	*Characidae*	*Colosoma brachypomum (Peter. 1852)*	Cá chim trắng	x		x	x	x		x	X
21	*Cichlidae*	*Oreochromis niloticus (Linnaeus.1757)*	Cá rôphi	x	x	x	x	x	x	x	X
22	*Cichlidae*	*Oreochromis spp.*	Cá diêu hồng	x	x	x	x				X
23	*Clariidae*	*Clarias macrocephalus (Gunther.1864)*	Cá trê vàng	x	x	x	x	x	x	x	X

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
24	*Clariidae*	*Clarias batrachus (Linnaeus.1758)*	Cá trê trắng	x	x	x	x	x	x	x	X
25	*Clariidae*	*Clarias gariepinus (Burchell. 1815)*	Cá trê phi	x				x			
26	*Cobitidae*	*Botia modesta (Bleeker. 1865)*	Cá heo vạch	x							
27	*Cobitidae*	*Botia helodes (Sauvage. 1876)*	Cá heo rừng	x							
28	*Cyprinidae*	*Esomus metallicus (Ahl. 1924)*	Cá long tong sắt	x	x	x	x	x	x	x	X
29	*Cyprinidae*	*Rasbora aurotaenia (Tirant.1885)*	Cá lòng tong đá	x	x	x		x			X
30	*Cyprinidae*	*Rasbora borapetensis (Smith. 1934)*	Cá lòng tong đỏ đuôi	x	x	x	x	x	x	x	
31	*Cyprinidae*	*Rasbora paviei (Tirant.1885)*	Cá lòng tong pavi	x	x	x	x	x			
32	*Cyprinidae*	*Rasbora trilineata (Steindachner. 1870)*	Cá lòng tong sọc			x		x			
33	*Cyprinidae*	*Cyprinus carpio (Linnaeus.1758)*	Cá chép	x	x	x	x	x	x	x	X
34	*Cyprinidae*	*Cyclocheilichthys repasson (Bleeker. 1853)*	Cá ba kỳ	x							
35	*Cyprinidae*	*Barbodes gonionotus (Bleeker.1850)*	Cá mè vinh	x	x	x	x	x	x	x	X
36	*Cyprinidae*	*Hampala macrolepidota (Valenciennes.1842)*	Cá ngựa nam	x				x	x		
37	*Cyprinidae*	*Hampala dispar (Smith.1934)*	Cá ngựa chấm	x				x	x		
38	*Cyprinidae*	*Systomus orphoides (Valenciennes. 1842)*	Cá đỏ mang	x		x					
39	*Cyprinidae*	*Puntius brevis (Bleeker. 1860)*	Cá dầm đất		x	x	x		x	x	
40	*Cyprinidae*	*Cirrhinus mrigala (Hamilton.1822)*	Cá trôi trắng	x	x	x	x	x	x	x	X
41	*Cyprinidae*	*Ctenopharyngodon idellus (Cuvier & Valenciennes.1844)*	Cá trắm cỏ	x	x	x	x	x	x	x	X
42	*Cyprinidae*	*Aristichthys nobilis (Richardson. 1844)*	Cá mè hoa	x	x	x	x	x	x	x	X
43	*Cyprinidae*	*Hypophthalmichthys molitrix (Cuv & Val.1844)*	Cá mè trắng	x	x	x	x	x	x	x	X
44	*Cyprinidae*	*Osteochilus hasseltii (Valenciennes. 1842)*	Cá mè lúi	x		x			x	x	
45	*Cyprinidae*	*Osteochilus waandersii (Bleeker. 1852)*	Cá mè lúi nâu	x							

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
46	*Cyprinidae*	*Labeo rohita (Hamilton. 1822)*	Cá trôi đen (rohu)	x				x	x	x	
47	*Eleotridae*	*Oxyeleotris marmoratus (Bleeker.1852)*	Cá bống tượng	x		x	x	x	x	x	X
48	*Helostomatidae*	*Helostoma temmincki (Cuvier. 1831)*	Cá mùi		x	x			x	x	X
49	*Hemiramphidae*	*Hyporhamphus limbatus (Valenciennes. 1846)*	Cá k m dưới chậu	x	x			x			
50	*Loricariidae*	*Hypostomus plecoftomus (Linnaeus.1758)*	Cá tỳ bà/lau kiếng	x	x		x	x		x	X
51	*Mastacembelidae*	*Macrognathus siamensis (Gunther.1861)*	Cá chạch lá tre	x	x	x		x		x	
52	*Mastacembelidae*	*Mastacembelus favus (Hora.1924)*	Cá chạch bông					x		x	
53	*Mastacembelidae*	*Mastacembelus armatus (Lacepede.1800)*	Cá chạch lấu	x		x		x	x	x	
54	*Mastacembelidae*	*Mastacembelus circumcinetus (Hora. 1942)*	Cá chạch khoang	x				x			
55	*Nandidae*	*Pristolepis fasciatus (Bleeker.1851)*	Cá rô biển	x		x		x	x	x	X
56	*Notopteridae*	*Notopterus notopterus (Pallas. 1780)*	Cá thát lát	x						x	X
57	*Belontiidae*	*Trichogaster trichopterus (Pallas.1770)*	Cá sặc bướm	x	x	x	x	x	x	x	X
58	*Belontiidae*	*Trichogaster microlepis (Gunther. 1861)*	Cá sặc điệp	x	x	x	x	x	x	x	X
59	*Palaeomonidae*	*Macrobrachium sp.*	Tép	x	x	x	x	x	x	x	X
60	*Siluridae*	*Kryptopterus moorei (Smith.1945)*	Cá trèn mo	x				x	x	x	
61	*Siluridae*	*Ompok bimaculatus (Bloch.1797)*	Cá trèn bầu	x		x		x		x	
62	*Synbranchidae*	*Monopterus albus (Zuiew.1793)*	Lươn	x	x	x		x	x	x	X
63	*Synbranchidae*	*Ophisternon bengalensis (M`Clelland. 1845)*	Lịch	x					x		
Total				53	28	34	25	45	33	36	27

Evaluating the Relationship Between Semi-Intensive Aquaculture and Natural Biodiversity

Mitigating Negative Environmental Impacts/Activity/09MNE06UM

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The effects of aquaculture on biodiversity have been the subject of much examination, but most of the focus has been on two particular aquaculture systems: shrimp and salmon. However, these are not among the most common species grown in aquaculture, or the most common systems used. Many aquaculture systems use semi-intensive culture to produce fish at a lower level of intensity and use more natural systems, often in ponds or other containers. Semi-intensive aquaculture has a different potential impact than intensive aquaculture, and the specific impact in this area has not been well defined. The role of intensification in aquaculture and agriculture is the subject of much debate today, so this is a good time to consider the relationship between lower intensity aquaculture and biodiversity as a part of that debate. This symposium is proposed to identify and illustrate the main impacts of semi-intensive aquaculture on biodiversity, and to seek means of reducing these impacts of aquaculture expansion on organisms.

As a result of this symposium, a number of papers were prepared for the final publication. Originally we intended to do this in book form, but after some discussion with authors, publishers, and editors, we decided to publish them as a special edition of *Reviews in Aquaculture*. The decision on publishing venue delayed the completion of these reports beyond the planned date, but as of 15 December 2011, we have 7 of the manuscripts submitted to the journal and out for review, and there are 3 others that are still being edited. We also added one new plan for publication, which was to prepare a shorter version of the reports as a contribution from the group to *Science* or *Nature*. So far, we have drafted a version of this manuscript and it is in its second round of editing. That paper, which will be submitted to *Science* as a contribution to their Policy Forum, should be completed by January 15 and submitted then.

PAPERS PRESENTED

The Effects of Semi-Intensive Aquaculture on Biodiversity: In Nearshore And Inland Waters: An Overview

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The effects of aquaculture on biodiversity have been the subject of much examination, but most of the focus has been on shrimp and salmon. These are not among the most common species grown in aquaculture, nor the most common systems used. Many aquaculture systems use semi-intensive culture to produce fish at a lower level of intensity and use more natural systems, often in ponds or other containers. Positive impacts of aquaculture on biodiversity include cultured seafood reducing pressure on overexploited wild stocks, stocked organisms enhancing depleted stocks, increased production, and species diversity caused by aquaculture, and replacing more destructive resource uses with employment in aquaculture. Negative impacts of aquaculture include invasive species established by escapement from aquaculture, eutrophication from effluents, conversion of sensitive land, use of fishmeal, and transmission of diseases to wild fish. Some of these impacts, especially use of fish meal and transmission of disease, are much less common in semi-intensive aquaculture systems.

Integrated Multi-Trophic Aquaculture: Environmental Biomitigation and Economic Diversification of Fed Aquaculture by Extractive Aquaculture

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Integrated multi-trophic aquaculture (IMTA) seeks to engineer intensive fed aquaculture (e.g., finfish or shrimps) by biodiversifying it with extractive aquaculture of species utilizing the inorganic (e.g., seaweeds) and organic (e.g., suspension- and deposit-feeders) excess nutrients from fed aquaculture for their growth.

The combination fed/extractive aquaculture aims to biodiversify food production systems to provide both biomitigative services to the ecosystem and improved economic farm output through the co-cultivation of complementary species. Through IMTA, some of the food, nutrients and by-products considered "lost" from the fed component are recaptured and converted into harvestable and healthy seafood of commercial value, while biomitigation takes place (partial removal of nutrients and CO_2, supply of oxygen, and beneficial species interactions/controls). Some of the externalities of fed monoculture are internalized, hence increasing the overall sustainability, profitability and resilience of aquaculture farms.

A major rethinking is needed regarding the definition of an "aquaculture farm" (reinterpreting the notion of site-lease areas) and regarding how it works within an ecosystem, in a broader framework of Integrated Coastal Zone Management (ICZM). The economic values of the environmental/societal services of extractive species should be recognized and accounted for in the evaluation of the true value of these IMTA components. This would create economic incentives to encourage aquaculturists to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems should be considered as candidates for nutrient/carbon trading credits within the broader context of ecosystem goods and services.

Our research is also establishing appropriate performance measures regarding environmental mitigation by investigating the responses in wild species (microbial and higher trophic levels) inhabiting the surrounding environment to determine if they can be used as valid indicators of nutrient cycling for aquaculture operations. Measures of diversity, abundance, colonization rates and individual species health (e.g. growth, reproductive output, immune responses) are all potential indicators of how a farm may function with respect to nutrient loading. While organic loading has been associated with benthic impacts (e.g. anoxia and hydrogen sulfide release), there have also been occurrences of moderate enrichment, promoting localized increase in biodiversity and abundance of wild species, as a natural response to changes in nutrient availability and niche space utilization. Changes in the rates and conditions under which these influences occur have the potential to provide direction for aquaculture management and improved IMTA farm design. Long-term planning/zoning promoting biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and management frameworks.

Aquaculture Effluents and Water Pollution

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Aquaculture facilities typically discharge into natural waters. Their effluents are enriched with nitrogen, phosphorus, organic matter, and suspended solids because fertilizers and feeds are used to enhance production above natural productivity. Generally, 20 to 40% of nitrogen and phosphorus applied to ponds in feed is recovered in harvested fish. In shrimp ponds, phosphorus recovery is 10 to 15%, but nitrogen recovery is about the same as in fish ponds. Bottom soils adsorb phosphorus, and denitrification and ammonia volatilization also occur in ponds. Usually, less than 30% of nitrogen and 10% of phosphorus applied to ponds exits in effluent. In raceway culture, nitrogen and phosphorus in uneaten feed and feces can be partially removed before effluents enter natural waters. However, in cage culture, nitrogen and phosphorus not recovered in fish at harvest enters the water body. Large aquaculture facilities or clusters of many small ones contribute considerable amounts of nitrogen, phosphorus, and certain other potential pollutants to receiving waters.

Aquaculture facilities contribute particularly to eutrophication of natural water bodies. Eutrophication is undesirable for other water users, but it also can be harmful to aquaculture facilities such as cage farms and shrimp farms that use the same water body as water supply and effluent recipient. Many countries have imposed regulations on aquaculture effluents. These may include limits on feed inputs, specifications for site selection, and effluent water quality standards. Aquaculture “eco-label” certification programs are being established in response to consumer demand for “environmentally-friendly” products. These programs may include effluent standards that limit discharge of nitrogen and phosphorus. Compliance with effluent regulations and “eco-label” certification program standards usually require installation of best management practices (BMPs) to limit discharge of nitrogen and phosphorus. Some examples of these BMPs are use of high-quality feeds that have no more nitrogen and phosphorus than required, conservative feeding practices, use of adequate mechanical aeration to oxidize waste in ponds, and discharge of effluent through a sedimentation basin. Some large producers also are voluntarily adopting BMPs independently of regulations or participation in “eco-label” certification. Studies of the environmental benefits of regulations, certification, and BMPs are few, but "responsible aquaculture" programs seem to be gaining popularity with seafood purchasers and consumers.

Transboundary and Emerging Diseases Of Freshwater Farmed, Ornamental and Wild Fish

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Aquaculture offers a solution to many of the food and nutrition security issues facing the growing human population. It bridges the gap between stagnating yields from capture fisheries and an increasing demand for fish and fishery products. It also offers opportunities to reduce poverty, increase employment and community development and reduce overexploitation of natural aquatic resources, thus creating social and generational equity, particularly in developing countries. Increased focus on aquaculture as solution to the demand and supply gap of aquatic products in the future will undoubtedly increase transboundary movement of live aquatic animals and their products. This carries an increasing biosecurity risk, particularly associated with introduction and spread of pathogens.

Transboundary aquatic animal diseases are highly contagious with strong potential for rapid spread irrespective of national borders. They pose a significant threat to the aquaculture sector and have major social, economic and environmental implications. These include loss of important animal protein source in human diet; direct and indirect impacts on output, income and investment; increased operating costs; restrictions on trade; impacts on biodiversity; loss of market share or investment; loss of consumer confidence; and in some cases, collapse of the sector. Managing aquatic animal health and biosecurity in aquaculture is particularly challenging because of the great diversity of the sector in terms of species cultured, the range of culture environments, the nature of containment, the intensity of farming practices and the variety of culture and management systems.

This presentation focusses on two transboundary and emerging/re-emerging freshwater fish diseases, epizootic ulcerative syndrome (EUS) and koi herpesvirus (KHV), which require focussed attention in the coming years to protect a major freshwater aquaculture sector from biosecurity emergencies. Freshwater aquaculture is the major contributor to “food fish” production; susceptible hosts to EUS and KHV rank amongst the world’s most important aquaculture species. These diseases are also important to the ornamental fish industry. The threats posed by EUS and KHV to freshwater farmed, ornamental and wild fish and freshwater resources are explored in this paper. Institutional responses and biosecurity measures to protect and prevent, two major lines of defence, against pathogen aggression, are also explored in this paper.

Applying Environmental Footprint Concept for Biodiversity Conservation in Semi-Intensive Aquaculture

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Aquaculture is of great importance worldwide, serving as an alternative source to traditional food production systems and helping supply the expansion of human population. Increase of global aquaculture production is achieved by intensification of farming systems, including increased farm size, material inputs, energy demands, and effluent discharge. The intensification has generated global concerns over its negative environmental impacts on the environment, aquatic ecosystems and human livelihoods in coastal areas. The negative effects of intensive aquaculture on biodiversity have been the subject of much recent debate. The debate is over whether semi-intensive aquaculture at a lower level of intensity and using more natural systems should be promoted to conserve biodiversity while still producing enough food. Thus, evaluation of environmental performance on different semi-intensive aquaculture systems is highly demanded. This overview examines impacts of semi-intensive aquaculture systems on biodiversity conservation from an environmental footprint perspective.

Environmental Performance

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In aquatic systems, as soon as feeds or wastes enter the water column, in situ mineralization occurs. The fraction of the produced wastes that is discharged depends on farm type, culture density, feed composition and water renewal rate. The effects of these factors on waste discharge are reviewed. All possible combinations of these factors result in large differences in the type and amount of waste products discharged to neighboring surface waters from aquaculture operations. Few farms discharge directly to a sewage system or operate an on-farm water purification system to deal with the discharged nutrients. Using a fraction of the otherwise discharged waste as an input for other cultures is possible, but also rarely practiced. In farms applying recirculating aquaculture system (RAS) technology and relying on nitrification and denitrification, nearly all wastes produced on-farm are mineralized, resulting in a stabilized sludge which represents on a dry weight basis 4 to 8% of the feed input. The semi-closed nature of RAS farms also minimizes the possible introduction and dissemination of diseases and parasites and the use of disinfectants and antibiotics. A small water exchange also reduces opportunities for culture animals to escape. With the exception of some extensive production systems, pond, cage or raceway operations discharge more nutrients and use more water per kg fish produced than RAS. The challenge is to make all future aquaculture farms equally efficient as RAS in dealing with waste discharge. This can be done by making aquaculture operations either more or less intensive. Each approach has its advantages and disadvantages and is reviewed in terms of water use, nutrient utilization and discharge, and energy use.

Antimicrobial Use In Aquaculture And Microbial Diversity

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Antimicrobials are widely used in salmon aquaculture. This use in the aquatic environment can potentially decrease bacterial diversity by eliminating susceptible organisms and simultaneously selecting for resistant ones. These effects and the emergence of antimicrobial resistant bacteria are directly linked and proportional to the amounts of antibiotic used in a particular geographical location. Studies of salmon aquaculture in Chile strongly indicate that the amounts of some antimicrobials, including tetracyclines, quinolones, and florfenicol, used in this industry are larger than those used in human medicine and other veterinary activities. This use in salmon aquaculture makes it the most important current and future selective pressure on the development of antimicrobial resistance in this country. Studies of sediments from salmon aquaculture-impacted and non-impacted sites indicate that these sediments appear to contain sufficient amounts of antimicrobials to exert selective pressure upon the bacteria contained in them.

Molecular analysis of bacteria isolated from these sediments has revealed that their genomes contain a variety of antimicrobial resistance genes coding for resistance to tetracycline, quinolones and florfenicol. These resistant bacteria can be selected in vitro, and probably in situ, by the presence of residues of antimicrobials in the sediments. The occurrence of some of these genes in genetic elements such as integrons, coupled to the presence of residual antibiotics in the sediment, also indicate that the potential exists for dissemination of these resistance determinants among bacterial populations by horizontal gene tranfer. This potential ability is consistent with information indicating that bacteria from aquatic environments and terrestrial environments including human pathogens share antibiotic resistance determinants and the mobile genetic elements harboring them.
In summary, injudicious use of antimicrobials in aquaculture decreases bacterial diversity, selects for bacteria resistant to these antimicrobials and is associated with potentially negative impacts on piscine and human health.

Primary Questions Of Nutritional Physiology That Would Combine The Whole Life Cycle In Culture Of South American Pseudoplatystoma Destined For Conservation And Industrial Purposes

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The genus Pseudoplatystoma contains eight species of catfishes, and they belong to largest migratory species in South America. These species have been decimated in the wild due to overfishing and environmental changes affecting their reproduction. They attract commercial interests, both for industrial culture and ornamental trade. We summarize the current understanding of the nutrition related physiology of these species, identify shortcomings and suggest further research. Examination of the olfactory system in early ontogeny suggests that larvae are nocturnal and are guided by their sensory system in feeding. We have concluded that larval catfish grown solely on Artemia naupli outperform fish offered formulated diets and live Tubifex, although cannibalism was lower in fish fed purified dipeptide based diets. To evaluate the protein and lipid requirement of Pseudoplatystoma, nine semi-purified casein-gelatin-lecithin based diets containing three levels of protein (40-50%) and three levels of lipid (12-20%) were tested. Juvenile fish were fed at a restricted-readjusted feeding rate for 8 weeks. The diets resulted in an average body weight increase of 21.2 ± 2.9 fold. The feed conversion ratio was affected by the dietary lipid level. At the 40% protein level, increasing the level of dietary lipid had a positive effect on final weight (protein sparing effects). Whole body protein and moisture contents were affected by the dietary level of lipid. Ash content was not affected by the dietary protein/lipid levels whereas several mineral levels, Na, K, B, and Mn were affected. Whole body lipid content positively correlated with the level of dietary lipid. Fatty acid composition of the whole body was affected by the dietary lipid level in the case of both neutral and phospholipids. Polyunsaturated fatty acids increased with increasing levels of dietary lipid while saturated fatty acids decreased. Our preliminary results suggest that surubim can utilize a high level of dietary lipid, and the optimum protein/lipid ratio might be close to 45/16%. We also used a stable isotope labeled amino acid (15N) to examine differences in the protein turnover ratio among groups fed diets with distinct levels of proteins/lipids. Studies on effect of broodstock feeding were inconclusive as a protein level in the range of 28 to 40% did not appear to affect gonad maturation. No viability of eggs was examined as a result of the variability in the composition of the diets. We ultimately discuss the implications of these findings for further expansion of the management programs, aquaculture and aquarium trade.

The Social and Economic Impacts of Semi-Intensive Aquaculture on Biodiversity

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As aquaculture has become more intensive, so have its impacts on the environment and biodiversity. There is growing concern and debate about the impacts of intensive aquaculture on biodiversity. As a result, semi-intensive aquaculture is being considered as an alternative since it will have different and lesser potential impacts than intensive aquaculture and use more natural systems. The biophysical impacts of aquaculture on biodiversity have been examined but there is only limited understanding of the social and economic impacts, especially in a shift from intensive to semi-intensive aquaculture systems. Aquaculture can provide improvements in quality of life through employment and income; however it can also have negative impacts as a result of environmental damage, changes in property ownership patterns, displacement of traditional users, and economic losses. This paper will examine the social and economic impacts of moving from intensive to semi-intensive aquaculture systems, especially in developing countries. Recommendations will be presented on how to minimize social and economic disruptions from lower intensity aquaculture and on biodiversity.

Aquaculture For The Conservation Of Native Fish Species In Southeastern Mexico

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Populations of native species of fish have been severely depleted in Southeastern Mexico, particularly in the State of Tabasco where the consumption of fish is culturally a tradition. Exploitation is intensive in those species with high values in the market; snooks, tropical gars and native cichlids are highly appreciated in the region, increasing the fishing pressure as human population rises. Tabasco is located in a very large floodplain and human activities – such as cattle ranching and agricultural practices- have turned vast areas of wetlands into ranches or farming land. This loss of environments for feeding, spawning, or hiding have also impacted fish populations. In Mexico, aquaculture has focused mainly in the production of introduced species, been tilapias, carps, rainbow trout, and shrimps the main species cultivated. In our region tilapia and shrimp culture are the center of attention. However, in our laboratory, since 1985, we initiated studies regarding the biology and ecology of native species aiming to generate enough information in order to propose aquacultural practices. To date, we have generated the complete technological package for tropical gar (Atractosteus tropicus) culture. Regarding the freshwater cichlids castarrica (Cichlasoma urophthalmus), tenguayaca (Petenia splendida), and paleta (Vieja synspilla), we have partly generated the culture cycle in captivty, but more research is needed for culture systems and diets. Our latest incursions are with three species of snooks, (Centropomus undecimalis, C. parallelus, and C. Poeyi). So far, we have successfully induced spawning, but feeding of the larvae is still a problem. Few experiments regarding growth have been implemented and more research is needed regarding this group of fishes. In our laboratory we produce a small amount of juveniles of tropical gar (200,000) and native cichlids (300,000) per year. Most of them are used for grow-out, but part of the production is used for re-stoking in areas where populations have been depleted. Genetic variability is taking into account by using broodstock from different areas of the region. With the native cichlids, we have compared reproductive performance and growth in captivity using lots from four different areas.
Our extension efforts have focused on technology transfer using workshops and direct training in the field, regarding larval production and growth of gars and cichlids. Many local farmers prefer the use of native species in their farms, but research is needed to significantly improve the culture of these fish in order to compete with tilapias.

Understanding the Basic Biology and Ecology of Invasive Nile Tilapia: The Role It Plays in Sustainable Aquatic Biodiversity

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Sustainable aquatic biodiversity is a complex process of understanding species physiological and behavioral capabilities, how these species respond to a non-native environment and its fauna, the economics associated with aquaculture, and social and philosophical realities. Herein we review our experience with an established population of Nile tilapia (Oreochromis niloticus) in coastal Mississippi. We set our review in context with other aquaculture, ballast water and aquarium trade introductions, some of which have trivial influences whereas other have significant influences on coastal and freshwater environments and native fauna. We argue that development of a complete understanding of the basic biology of aquaculture species is imperative to proactively protect aquatic biodiversity. To have real "responsible" aquaculture requires tradeoffs between establishment of appropriate best management practices to protect the environment and its native fauna balanced with the economics of industry growth.

Tilapia And Aquaculture: A Review Of Management Concerns

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The demand for seafood coupled with the decline of fisheries species worldwide due, in part, to overfishing and habitat degradation has resulted in an increase in land-based and offshore aquaculture facilities. Globally, tilapia are very important aquaculture species with China, Philippines, Taiwan, Indonesia, and Thailand responsible for nearly 76% of the total worldwide production. The United States is a major importer of tilapia products and within the United States, tilapia production has continued to grow since the early 1990s with Oreochromis aureus, O. mossambicus, O. niloticus, and various hybrid combinations of the three being the primary aquaculture forms. Thus the potential for the introduction and establishment of feral populations of tilapia has increased following this growth in aquaculture interests. Wild-caught individuals of the primary aquaculture forms have been documented in 27 states (USGS NAS) with populations established in 14. Similarly, commercial tilapia production has been reported in 20 states (2007 Census of Agriculture; American Tilapia Association, Fitzsimmons pers. comm.) with 10 of those (AZ, CA, CO, FL, ID, LA, MS, NC, PA and TX) also having established populations of feral tilapia. Six states (AL, AR, MA, NM, NY, and WI) have reports of wild-caught tilapia but no established populations and the remaining four states (IA, MN, MO, and VA) have no reports of wild-caught tilapia. National management recommendations and policies for regulating many non-native taxa exist; however in the case of tilapia and their ties to aquaculture, permitting requirements, and regulatory jurisdiction varies among states such that unified management policies are unattainable. Several states have imposed special restrictions on tilapia aquaculture facilities to minimize the potential of escape (screened effluent, sterilized effluent, culture ponds encircled by levees) while others force accountability for releases through monetary means (insurance bonding). There are few if any requirements in place to provide protection against natural disasters (flooding, hurricanes) although emergency management plans are advocated by nearly all regional and national policy advocates.

Reaching Fish Farms Through AquaFish CRSP Technology Transfer: Elimination of MT from Intensive Masculinization Systems Using Bacterial Degradation

Mitigating Negative Environmental Impacts/Study/09MNE07UA

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OBJECTIVES

The general objective of this project is to transfer A&F CRSP-generated technology to the private sector, ensuring the development of sustainable tilapia aquaculture in Southeastern Mexico and Central America. The specific objectives are:

1. Evaluate combination of bacteria that best degrade MT in tilapia masculinization systems.
2. Transfer MT degrading technology using bacteria to a large hatchery.
3. Develop written materials for the dissemination of these protocols and train tilapia farmers in the use bacterial bio-flocks as MT-degrading entities and probiotics.
4. Continue evaluation of bacterial combinations that improve degradation of MT and that can serve as probiotics

INTRODUCTION

Aquaculture industry considers different technologies in order to improve food production for the increasing human needs. One alternative for male monosexual population production is the utilization of synthetic steroids. The aquaculture industry commonly uses steroids including the 17 α – methyltestosterone (MT), miberolone, fluoxymesterone, nortestosterone acetate, 17 α – methyldihydrotestosterone and norgestrel. MT is the most common form in worldwide use (Hurtado, 2005; López et al., 2007). Specifically, MT is a strong androgen widely used for tilapia masculinization. Around 90% of MT used during masculinization treatments is degraded during the first 24 h and only 1% is remaining 3 weeks later in the fish body (Raisz et al., 2006; Contreras, 2001).

Other natural and synthetic chemicals present in the environment like 17α - estradiol, estriol, estrone, progesterone, testosterone and phytoestrogens mimic hormonal actions. These chemicals actually are considered a worldwide issue because they could disturb sexual characteristics in fish, amphibians, reptiles and mammals (Toft et al., 2004; Argemi et al., 2005; Bracho, 2007). These compounds are consider Endocrine Disrupting Chemicals (or Compounds) or EDCs because are exogenous chemicals which could promote endocrine system alterations and adverse effects on individuals, broods and populations health (Anonymous, 2002). This phenomenon includes reproductive system dysfunction, neoplasia, malformations, neurotoxicity, and decreasing immune response, promoting difficulties to detect possible causes and effects (Swan et al., 2003; Rivas et al., 2004).

In order to decrease environmental impacts of these compounds, Best Management Practices for aquaculture include the use of Recirculation Aquaculture Systems, (RAS). RAS decreases the total waste production, saving water and decreasing waste in the fish culture systems improving water quality for reutilization. Another method for chemical elimination of hormones is the use of granular activated charcoal to absorb the compounds. Finally, phytosteroids have been tested from vegetal origin; these compounds mimic fish steroids and sometimes have similar impacts on gonadal development (Contreras, 2001; Campos, 2004).

Microbiological degradation processes have been widely studied in recent years; microorganisms have biodegrading features for many pollutants. Microorganisms accumulate, transform or degrade different pollutants including petroleum hydrocarbons. In order to decrease risks for human and environment health the main scope for this study was to determine bacterial strains able to degrade 17 α – methyltestosterone (MT). These bacteria were isolated from a biofilm obtained from a RAS used for fish chemical sex reversion.

MATERIALS AND METHODS

Bacterial strains selection

Strains were obtained from the Microbiology Laboratory at the División Académica de Ciencias Biológicas at UJAT. These strains were originally isolated from biofilms obtained from biological filters used in a tilapia (*Oreochormis niloticus*) masculinization system. Strains of *Pseudomonas aeruginosa, Pseudomonas fluorescens, Bacillus cereus* and *Bacillus subtilis* were selected according to previous experimental data showing potential to degrade MT under culture conditions where these steroids were used as carbon and energy source.

Bacterial strains adaptation

The four bacteria strains were subjected to adaptation to MT as main source of carbon and energy during 10 days-period, previous to experimental procedure. Each bacterial strain was inoculated in a glass beaker containing 100 mL of liquid mineral culture media containing 40 mg of MT (Sigma-Aldrich, Inc.). according to the procedure presented by Pérez *et al*., (2006), Yamanaka *et al.,* (2007) and Montpas *et al*., (1997) respectively (Table 1). All treatments were evaluated in triplicate, including control treatments containing MT and no bacteria, and without MT and bacteria present. Cultures were incubated at 30 ± 1 ºC in an orbital shaker incubator 175 rpm, (PolyScience®) (Perez *et al.,* 2006; Yamanaka *et al.,* 2007).

During the experimental phase, the number of viable cells was estimated by conventional plate counting technique. MT-enriched liquid mineral medium was used adding 15 g per liter of bacteriological agar (BIOXON®). Each sample was serially diluted (1:10) in a sterile 0.85% saline solution to obtain a 10^{-5} final dilution. For each diluted sample, 100 µl were inoculated in the center of each Petri dish and extended using a sterile Drigalski spreader. Inverted Petri plates were incubated for 48 h to 30 °C ± 0.5 ºC and the count were estimated using a Darkfield Quebec colony counter (Bracho *et al.,* 2004).

Table 1.- Chemical composition of the culture media used g/L. (-) indicated the absence of the mineral compound.

Minerals	*Bacillus*	*Pseudomonas*	Modificated
NH4Cl	-	0.1	0.005
$MgSO_4 . 7H_2O$	0.1	0.05	0.1
$K_2HPO_4 . 3H_2O$	6.3	0.1	6.3
$KH_2PO_4 . 3H_2O$	1.83	0.05	1.83
$FeSO_4 . 7H_2O$	0.1	0.001	0.1
$CaCl_2$	0.1	0.001	0.1
$(NH_4)2SO_4$	1	-	1
KCl	-	0.01	0.01

Determination of MT to evaluate degradation capacity

The experiment had 4 treatments with controls: 1) *Pseudomonas aeruginosa and Pseudomonas fluorescens; 2) Bacillus subtilis and Bacillus cereus; 3) Pseudomonas aeruginosa and Bacillus cereus; and 4) Pseudomonas aeruginosa, Pseudomonas fluorescens, Bacillus subtilis and Bacillus cereus* mineral culture media and MT, without bacteria; and 2) A flask with mineral culture media without MT and with the corresponding bacteria according to the treatment. Each treatment was performed in triplicate, but the treatment control had only one experimental unit.

Each treatment was inoculated with 1mL of a bacterial suspension equal to the Turbidimetry McFarland scale of 0,5 and corresponding to a population of 1,5 x 10^8 UFC/ 100 mL. The inoculum was incubated at 30°C ± 1 º C with rotary agitation at 175 rpm (PolyScience®) during 22 days.

The number of microorganisms in each treatment was measured daily through viable counting with the superficial extension technique. The media used in this phase was a mineral media enriched with MT with the addition of 15 g of bacteriological agar (BIOXON®) by liter of media. Serial dilutions were made from 1 mL of sample in 9 mL of sterile saline solution at 0,85% (10-1) up to a dilution of 10^6. From each dilution 100 µL was inoculated in the center of a Petri dish, extending over the media surface with a sterile Drigalski dipstick. The Petri dishes were placed in an inverted position for incubation at 30 °C ± 0.5 ºC. The dish readings were performed at 48 h using a Darkfield Quebec counter.

Elisa test or Immunoassay method (r-biopham)

Samples from each treatment were collected in order to determine MT concentrations at 0, 2, 6, 10, 16 and 20 days. All samples were stored in a freezer (-20 °C) in Eppendorf tubes until analysis. Samples were diluted in methanol at 40% up to a dilution of 10^6, in order to determine the maximum and minimum limits of MT in the calibration curve of the kit.

The quantitative measurement of MT was performed by the Elisa test or Immunoassay method (r-biopham): 50 µl of sample of each treatment were inoculated by duplicate. Each analysis had six standards in order to obtain the calibration curve of MT. Once the samples inoculated, 50 µl of the conjugate and 50 µl of the antimetiltestosterone (antibody) solution was added. Incubation was performed for 12-16 h at 2-8 º C. After incubation two distilled water rinses were completed, using a semiautomatic washer.

Following the wash step, 50 µl of substrate and 50 µl of chromogen were pipetted into each well and they were incubated in darkness for 30 minutes. Finally 100 µl of stop solution was added to each well and we proceeded to the reading with a spectrophotometer at an absorbance of 450 nm. The obtained data was analyzed with the software RIDA® SOFT Win in order to obtain the MT concentration in each sample. After obtaining the raw data the number was multiplied by the dilution factor.

RESULTS FOR OBJECTIVES 1 AND 4

The treatment which showed the greatest growth after 24 h and a greater number of cells was *P. aeruginosa* and *P. fluorescens.* With a growth curve of 30 days, the treatment with *B. cereus* and *B. subtilis* showed growth at 48 h with a duration of 22 days. Figure 1 shows the growth curves of the two finalized treatments.

DISCUSSION

Objectives 1 and 4

The results obtained with respect to the two treatments demonstrated bacteria growth in MT media (40 mg/100 ml) as the only carbon source. Yomokito et al. (2004) and Ke et al. (2007), observed bacteria growth and biodegradation from 100 mg/ 100 ml of 17 β – estradiol and 17α-methylestradiol and 3-methoxy-17b-hydroxy-1,3,5 (10),8(9)-d-4-estren (MHE) respectively. In both studies the strains came from activated sludge from a treatment plant with estrogen residues. Jiang et al. (2010), isolated *B. subtilis* as degrading of 17 β – estradiol at a concentration of 1 mg/100 mL which differs with our project. Due to this the strain was isolated in a mineral media with 50 mg/100 mL of

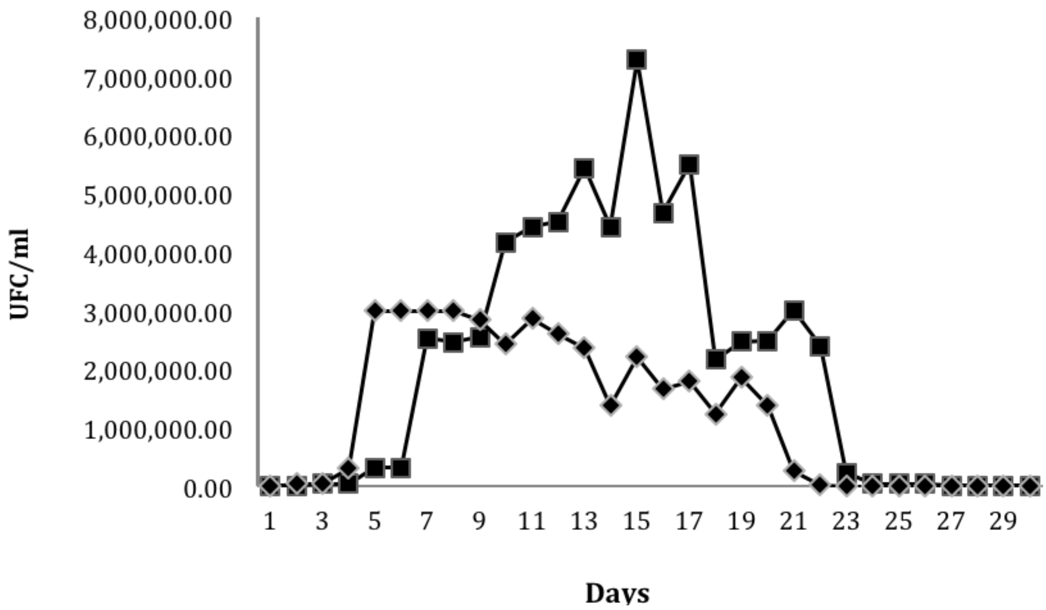

Figure 1. Average value of the microbial growth kinetics in mineral media enriched with 17α - methyltestosterone (MT), the values correspond to mean of triplicate measurements.■ *Pseudomonas aeruginosa* and *Pseudomonas fluorescens;* ♦ *Bacillus cereus* and *Bacillus subtilis*

estrogen plus 15 mL of activated sludge from sewage of a manufacturer of oral contraceptives in Zhejiang, China, performing successive cycles and changing the concentration up to 1 mg of estrogen.

Steroid biotransformations are important in the manufacture of drugs and hormones; anti-inflammatories, diuretics, steroids, anti-androgenic and anti-cancer agents and with some other applications (Moschet *el al*., 2009; Walaa *et al.*, 2009). The steroids biotransformation by bacteria and fungi have been suggested by Smith et al. (1998) and Walaa et al. (2009) investigating the transformation of progesterone by *Apiocrea chrysosperma, Botryosphaerica obtusa, Bacillus subtilis* and *Aspergillus niger*. Phelps and Popma (2000) mentioned that bacteria and fungi could be responsible of steroids metabolization and they assumed the existence of an androgen microbial degradation in the biofilters of the recirculation systems.

It has been proved that the genera *Nocardia, Bacillus subtilis, Mycobacterirum, Bacterium* and *Arthrobacter* act as estrone degrading. Lee and Liu, (2001), Weber et al. (2007); Shulan et al. (2007) and Jiang et al. (2010), have studied the steroids microbial degradation identifying: *Achromobacter xylosoxidans, Ralstonia sp*, *Raoultella thalpophilim* and *B. subtilis* as responsible for estrogens biodegradation, although the conditions of our experiment were different, the percentages of biodegradation were between 80 to 85%, which are similar to the above investigations.
The *Pseudomonas sp.* and *Bacillus sp.* have been used in the biodegradation of hydrocarbons, obtaining a good elimination rate, thus it is recommended that both microorganisms can be used for biodegradation of these compounds (Mohamad et al., 2004). Duarte and Gomes (2000) mentioned that degradation increased with a bacteria conjugate due to better degradation capacity with a wider range of action.

Objective 2. Transfer MT degrading technology using bacteria to a large hatchery

Work on this objective is still underway. During the extreme flooding in mid-2011, the hatchery at our demonstration farm partner was lost and the biofiltration system was destroyed. The operation has been moved to a second location that is significantly higher and should be above the flood stage that was breached in each of the last two years. We are collecting data in late 2011 and early 2012.

Objective 3. Develop written materials for the dissemination of these protocols and train tilapia

farmers in the use bacterial bio-flocks as MT-degrading entities and probiotics.

Work on this objective is nearing completion. A biofloc workshop was held in September 2010 at UJAT for hatchery managers who would be working with biofloc systems. Some were interested to use bioflocs to remove residual MT and other more specifically to produce bioflocs as a feed source. A Power Point presentation has been prepared and shared with the farmers.

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