

AQUACULTURE COLLABORATIVE RESEARCH SUPPORT PROGRAM

TWENTY-FIFTH ANNUAL TECHNICAL REPORT VOLUME II

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AQUACULTURE COLLABORATIVE RESEARCH SUPPORT PROGRAM
Twenty-Fifth Annual Technical Report – Volume II

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Introduction

The Aquaculture Collaborative Research Support Program (ACRSP) is funded by the United States Agency for International Development (USAID) under authority of the Foreign Assistance Act of 1961 (PL 87-195) as amended and by ACRSP participating universities and institutions. ACRSP is currently in its final year and will officially close on June 30, 2008.

A cohesive program of research has been conducted in selected developing countries and the United States by teams of US and host country researchers, administrators, students, and others. Currently operating under a no-cost extension granted under its fourth USAID grant since 1982, the ACRSP has been guided by the concepts and direction set down in the *Continuation Plan 1996* (USAID Grant No. LAG-G-00-96-90015-00).

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

REPORT SCOPE

This report, the *Twenty-Fifth Annual Technical Report*, describes research and outreach undertaken by the ACRSP during its final year. It includes projects funded in the Twelfth Work Plan (WP12) and its two addenda, available at pdacrsp.oregonstate.edu/pubs/work_plans/. This report is the last in the publication series of project reports for WP12, and for the ACRSP overall.

WP12 RESEARCH PROJECTS

The *Twenty-Fifth Annual Technical Report* contains the final technical reports for the WP12 research projects described in the *Twenty-Fifth Annual Administrative Report* (published 2007). In setting the conceptual framework for the final stage of ACRSP, WP12 focused research on sustainable aquaculture development in coastal and inland areas. Projects fit into one of three program areas:

- Production Technology
- Watershed Management
- Human Welfare, Health, and Nutrition

Projects encompass multiple investigations with each investigation focusing on any one of ten scientific themes. For project-level reporting, please refer to the *Twenty-Fifth Annual Administrative Report*.

WP12 SCIENTIFIC THEMES

Each of the ten WP12 scientific themes collectively cover economic growth, food security, and the wise use of natural resources in aquaculture:

Environmental Impacts Analysis (EIA)

With the rapid growth in aquaculture production, environmental externalities are of increasing concern. Determining the scope and mitigating or eliminating the negative environmental impacts of aquaculture—such as poor management practices and the effects of industrial aquaculture—are primary goals of the ACRSP.

Sustainable Development & Food Security (SDF)

Aquaculture is increasing in importance as a source for poverty alleviation and food security in developing regions of the world. A focal area of the program is to support efforts related to sustainable aquatic farming systems that can demonstrably ensure a reliable future food supply.

Production System Design & Integration (PSD)

Aquaculture is an agricultural sector with specific input demands. Systems should be designed to improve efficiency and/or integrate aquaculture inputs and outputs with other agricultural and non-agricultural production systems.

Indigenous Species Development (ISD)

Domestication of new and indigenous species may contribute positively to the development of local communities as well as protect ecosystems. At the same time, the development of new species for aquaculture must be approached in a responsible manner that diminishes the chance for negative environmental, technical, and social impacts. Efforts that investigate relevant policies and practices are encouraged while exotic species development is not encouraged.

Water Quality & Availability (WQA)

Aquaculture development that makes wise use of natural resources is at the core of the CRSP. Gaining a better understanding of water and aquaculture is a matter of great interest to the ACRSP. The range of possibilities is broad—from investigations that quantify such things as availability and quality to those that look into the social context of water and aquaculture, including water rights, national and regional policies (or the lack of them), traditional versus industrial uses, and the like.

Economic/Risk Assessment & Social Analysis (ERA)

Aquaculture is a rapidly growing industry; its risks and impacts on society need to be assessed. Significant issues in this arena include cost, price, and risk relationships; domestic market and distribution needs and trends; the relationships between aquaculture and women/underrepresented groups; and the availability of financial resources for small farmers.

Applied Technology & Extension Methodologies (ATE)

Developing appropriate technology and providing technology-related information to end-users are high priorities. The program encourages efforts that result in a better understanding of factors and practices that set the stage for near-term technology implementation and that contribute to the development of successful extension tools and methods.

Seedstock Development & Availability (SDA)

Procuring reliable supplies of high quality seed for stocking local and remote sites is critical to continued development of the industry. A better understanding of the factors that can contribute to stable seedstock quality and quantity for aquaculture enterprises is essential.

Fish Nutrition & Feed Technology (FNF)

Ways and methods of increasing the range of available ingredients and improving the technology available to manufacture and deliver feeds is an important theme. Better information about fish nutrition can lead to the development of less expensive and more efficient feeds. Efforts that investigate successful adoption and extension strategies for the nutritional needs of fish are also encouraged.

Aquaculture & Human Health Impacts (HHI)

Aquaculture can be a crucial source of proteins and micronutrients for improved human health, growth, and development. Conversely, human health can be negatively impacted by aquaculture if it serves as a direct or indirect vector for human diseases. There is also interest in better understanding the interconnectedness of such human health crises as AIDS/HIV and aquaculture production.

TWO VOLUME SET

The *Twenty-Fifth Annual Technical Report* is a two-volume set with the following coverage of scientific themes:

Volume I

- Environmental Impacts Analysis
- Sustainable Development & Food Security
- Production System Design & Integration
- Indigenous Species Development
- Water Quality & Availability

Volume II

- Economic Risk Assessment & Social Analysis
- Applied Technology & Extension Methodologies
- Seedstock Development & Availability
- Fish Nutrition & Feed Technology
- Aquaculture & Human Health Impacts

CITATION FORMAT

The appropriate citation for a report contained in this volume is, for example:

Diana, J. S., L. Theodore, T. Brookhart, and V. Schwantes. 2008. Assessment of Coastal and Marine Aquaculture Development for Low Trophic Level Species. In: L. Morrison and H. Eгна (Editors), *Twenty-fifth Annual Technical Report. Volume II. Aquaculture CRSP*, Oregon State University, Corvallis, Oregon, pp. 7–17.



Reports: Volume II

The 25ATR contains final technical reports for the WP12 research projects described in the 25AAR (published 2007). The WP12 final technical reports in this volume cover five research themes:

- Economic/Risk Assessment & Social Analysis
- Applied Technology & Extension Methodologies
- Seedstock Development & Availability
- Fish Nutrition & Feed Technology
- Aquaculture & Human Health Impacts

INVESTIGATION CODE

Each report is identified by a unique scientific-theme investigation code e.g., 12ERA1. In this code, "12" refers to WP12, the 3-letter acronym (e.g., "ERA") identifies the research theme, and the number (e.g., "1") identifies the sequential investigation number assigned within the research theme block.

TECHNICAL REPORT FORMAT

Although technical reports have been formatted for style, they are published as submitted. Figures and tables that did not follow *ACRSP Publication Guidelines* may have lost information during formatting. Figures reflect their original condition as submitted. Please contact the authors directly for questions about content, tables, or figures.

ASSESSMENT OF COASTAL AND MARINE AQUACULTURE DEVELOPMENT FOR LOW TROPHIC LEVEL SPECIES**THE STATUS AND FUTURE OF NEAR SHORE AQUACULTURE FOR LOW TROPHIC LEVEL SPECIES**

*Twelfth Work Plan, Economic/Risk Assessment & Social Impacts 1 (12ERA1)
Final Report*

Published as Submitted by Contributing Authors

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ABSTRACT

Many look to the production of low trophic species such as seaweed and bivalves in near shore ecosystems as a way to make aquaculture systems “sustainable.” Low trophic aquaculture systems are rapidly expanding worldwide in the near shore, and are touted as capable of solving eutrophication problems. After reviewing the literature to date on low trophic culture in near shore ecosystems, it is apparent that low trophic aquaculture can be done in an ecologically friendly way, but that our limited knowledge of near shore ecosystem functioning makes it difficult to say that any one system is truly ecologically, culturally and economically sustainable. After providing a review of the current literature on low trophic near shore aquaculture, we propose a theoretical model for its future continued development, called Low trophic, Ecological Aquaculture in the Near shore, or LEAN. This model moves away from the concept of sustainable development and focuses on the principles of ecological aquaculture developed by Barry Costa-Pierce, applying them specifically to near shore and low trophic aquaculture.

BACKGROUND

The body of literature on Low trophic, Ecological Aquaculture in the Near shore, or LEAN, is immense, as it is practiced in almost every country that has a coastline (Parsons et al. 2002; Nunes et al. 2003). Thus, the concept of LEAN was developed as a lens through which to view the literature to date, with the particular goal of identifying the types of low trophic near shore aquaculture systems that have the most promise.

LEAN systems include any method of cultivating plant or animal species that requires minimal to no outside energy or food inputs to foster adequate growth, is conducted in coastal estuaries, beaches, bays, inlets or lagoons that can be easily managed for human benefit with little invested capital or equipment, has minimal impacts on the environment, and can be integrated within local socio-economic and cultural structures.

The term sustainable is extremely important for authors attempting to redirect the focus and goals of aquaculture as it allows them to draw much needed connections between the goals of near shore aquaculture, and those of sustainable development and integrated coastal zone management. LEAN systems have the potential to be ecologically, socially, politically, and economically sustainable. However, we avoid blanket statements referring to low trophic near shore aquaculture as sustainable, even though much of the literature refers to it in this way.

We do not consider utilizing LEAN to treat the effluent from high trophic level aquaculture operations to be sustainable aquaculture because it directly supports usually unsustainable practices with large ecological footprints and intensive energy use. However, acknowledging that production of high trophic level fish and crustacean farming will continue, we feel it is important

to promote the use of low trophic species to treat effluent, essentially improving the overall sustainability of high trophic level systems by decreasing their ecological impacts.

Furthermore, it is difficult to find concrete evidence of any successful, large-scale aquaculture projects that are proven to be sustainable in the literature, most likely because researchers are still struggling to find accurate indicators of sustainability (Wilson, 2005). Thus, by using this term, we hold ourselves accountable for developing a framework by which to assess the sustainability of the projects we describe and propose here—framework that we are not convinced can be developed at this time.

Utilization of the near shore region for low trophic aquaculture production occurs in most parts of the world, from the west coast of British Columbia, Canada to the provinces of Southern China (Parsons et al., 2002; Nunes et al., 2003). There are numerous studies and reports in the academic and popular literature of LEAN pilot projects, as well as regional workshops and meetings held around the world to address programmatic development of sustainable aquaculture in the near shore region (Stead et al., 2002; Perez-Sanchez and Muir, 2003).

To a considerable degree, our view of the role of LEAN systems in aquaculture is similar to the role of artisanal fisheries in commercial fishing. Both provide social stability and economic values to small coastal communities. Neither is capable of major harvests to compete with intensive aquaculture or offshore fisheries. However, both play a major role in the livelihoods of small communities and low to middle income people. Adding this important social and economic value to the ecological role of low impact and often benign aquaculture makes LEAN systems particularly important to international development.

Evidence suggests that on-the-ground development of new technologies and systems for LEAN has either preceded or is occurring simultaneously with academic research of these systems. Many efforts to pursue low trophic level aquaculture in the near shore are done on a small-scale and in the economic and political shadow of intensive monoculture production models that continue to dominate the world export markets.

Intensive production models have created a predominant perception of how, where, and why aquaculture projects occur. This is a double-edged sword for the future development of low trophic aquaculture. The negative stigma associated with intensive fish farming has carried over to include less destructive, benign, if often beneficial, forms of low trophic aquaculture (Costa-Pierce, 2002b), stifling market development and potential investment (Hishamunda and Ridler, 2002). Many LEAN systems do not generate the degree of ecological destruction or socio-economic inequity associated with high trophic culture systems.

The number of species already used in LEAN projects is immense, though available data are highly variable (FAO, 2003). LEAN systems can be used for a variety of purposes: to clean up effluent from high trophic level aquaculture or other anthropogenic pollutants (Jiang et al., 2001; Jones et al., 2002; Troell et al., 2003; Kraemer et al., 2004); to sustain large commercial industries with seaweed and bivalve production (Lüning and Pang, 2003; WeiMin and Gibbs, 2005); to develop small-scale, sustainable integrated culture systems for local peoples (Rothuis et al., 1998); to reduce the impact of the aquarium trade on coral reefs (Ellis and Ellis, 2002); and to supplement or replace imperiled or over-exploited capture fisheries (Stotz, 2000).

LITERATURE SUMMARY

The relevant body of literature encompasses a variety of aquaculture production systems and an array of potential species for cultivation. Literature relevant to low trophic level aquaculture in the near shore can be found in many sources not overtly associated with aquaculture, yet critically related. Academic journals focusing on topics of estuarine science, nutrient cycling, water chemistry, shellfish ecology, fish ecology, fisheries management, coastal zone management, CO₂

sequestration, and wetland science and management contain studies relevant to LEAN. We searched the most recent (approximately 1999 to 2005) academic, governmental, and popular literature.

LEAN is often described using terms such as polyculture, integrated culture, sustainable aquaculture, efficient aquaculture, and low intensity aquaculture; and all of these terms were included in our searches. Organisms most commonly associated with these types of aquaculture include species of clams, mussels, oysters, scallops and other bivalves, seaweeds, mangroves, crustaceans, as well as a few species of herbivorous and omnivorous fish.

We narrowed our research by excluding all culture methods that utilized large levels of inorganic or synthetic fertilizers, required high protein feeds, used excessive antibiotics and/or pesticides, utilized intensive amounts of water or energy, or utilized species that were considered noxious to or highly competitive with endemic species. In doing so, our research yielded limited examples of canonical success stories with LEAN systems outside of small indigenous production systems. Literature searches were conducted using the University of Michigan's online journals database, Science Direct, Springer-Link, BIOSIS and Lexis Nexis. We also used electronic and manual reference tracking to find and procure documents. National and State government databases and FAO Fishstat provided the bulk of our quantitative data.

One-hundred ninety-three sources were reviewed as part of this study. They included books, academic and popular literature, government reports and databases, and online editorials; 158 of them focused on some aspect of LEAN aquaculture, while the remainder discussed integrated coastal zone management, application of sustainability principles to aquaculture, and antibiotic and pesticide use in aquaculture.

The following discussion pertains to those articles specific to LEAN aquaculture. Monoculture was discussed in approximately 65% of the articles and integrated or polyculture systems were less prevalent, referenced in 50%. Study types included experiments conducted both on-site and in the laboratory, case studies, social and/or economic studies, modeling studies, literature reviews, and position papers. Many papers focused on the developing world (73), followed by developed countries (49) and aquaculture worldwide (36). A primary goal was to analyze and categorize the components of the studies to identify gaps in the literature and research related to LEAN development.

Each article was categorized based upon the species of focus (crustacean, fish, algae/plant, bivalve, other, or general culture). Articles dealing with integrated culture of a low trophic organism (such as algae) with a high trophic organism (such as shrimp) were classified within categories corresponding to both crustaceans and algae/plants. Articles were also categorized under a primary focus within a broader purpose of research category (to increase/improve production, address environmental impact, address socio-economic impacts, or to manage aquaculture development). Many articles focusing on low trophic aquaculture in the near shore are interdisciplinary in nature, and could be listed under several foci and research purposes. The values found in Table 1 represent the prevalence, or absence, of topics discussed in the literature in regards to a particular species. Topics that are not addressed in the literature are coded 0, those that are discussed 1 to 6 times are coded 1 (low), 7-12 times are coded 2 (medium), and 13 and greater are coded 3 (high).

The results of this literature search (Table 1) showed few areas with high numbers of citations and many with few to no citations. The overall average ranking was 1.2 (low to medium). The four major topics all were ranked about equally between low and medium in citation frequency. Training programs, disease, and stock enhancement ranked lowest among the topics covered; exploring new species, coastal zone management, and policies were intermediate; and techniques, environmental effects, social and economic dimensions ranked highest. Very few studies focused on sponges, while fish, crustaceans, algae, and bivalves were studied with increasing emphasis.

As one might expect, given the methods to detect LEAN research, this literature focused mainly on algae and bivalve culture emphasizing ecological and social impacts, in contrast with typical aquaculture literature which focuses more on production enhancement and on fishes or crustaceans.

ECOLOGICAL, ECONOMIC, SOCIAL, POLITICAL, AND CULTURAL ISSUES

The development and potential sustainability of LEAN projects are heavily affected by a multitude of ecological, economic, social, political and cultural factors. The following section provides a synopsis of the issues that cause numerous LEAN projects to fail because they are not appropriately integrated into existing cultural, economic, and ecological structures and systems.

Ecological Issues

Myriad ecological factors affect the success of LEAN projects, similar to the ecological risks commonly associated with higher trophic level systems. While many projects strive for the ideals embodied in our definition of LEAN, the fractional understanding and evolving study of near shore ecosystem processes often complicates management of near shore projects.

LEAN can potentially pose substantial risk to the surrounding ecosystem if conducted errantly. For example, mussel farming with rafts in South Africa had significant adverse effects to benthic macrofauna and was the cause of eutrophication and algal blooms (Stenton-Dozey et al., 2001), although this was not the case when studying the impacts of mussel farming in the Adriatic Sea (Danovaro et al., 2004). Additional ecological impacts may include net loss of plankton, consumption of native pelagic fish and bivalve larvae, coastal eutrophication, benthic habitat destruction, decreased biodiversity and increased incidence of disease. Often, both high and low trophic level systems exceed sustainable production levels, resulting in deleterious effects on the surrounding ecosystem and the cultured species itself.

Water quality is often affected in the immediate vicinity of aquaculture production and may include sediment hypoxia and anoxia from organic enrichment, carbon and nutrient enrichment of the water column and benthos, and reduced dissolved oxygen from eutrophication (Frankic and Hershner, 2003). Nutrient additions in nutrient poor coral reef environments can favor algae and catalyze herbivore induced changes of the ecosystem (Bell and Gervis, 1999). The effects of chemicals leached from construction materials, antifoulants on nets and cages, and hormones are largely unknown, but assumed to be substantial (Naylor et al., 2000). Also unknown are the long-term effects that aquacultural pesticide and antibiotic use may have on the development of resistance in microbial communities within individual ecosystems (FAO, 2002; Chelossi et al., 2003). While historically this has not been a paramount concern, recent scares associated with bird flu and other lethal pathogens have reinvigorated the debate surrounding the use of antibiotics and pesticides in food production systems (Singer et al., 2003).

LEAN systems often have unanticipated effects on populations of native species, ecosystem structure, and biodiversity. Mussel farms in New Zealand were studied to deduce the level of egg mortality and recruitment effects on blue cod, as well as the food web effects of these systems (Gibbs, 2004). Trends indicated mussels hindered recruitment and redirected energy flows, however, obvious deleterious effects were not found for blue cod. Seaweed farms in Tanzania displaced native fish species in areas of high species diversity (Bergman et al. 2001). However, in areas of low species diversity, the opposite was found to be true: bivalve farming led to a more diverse fish assemblage as a result of improved habitat.

Organisms that escape from the culture area, whether native or exotic, may compete with or consume local organisms, disrupt breeding colonies and feeding grounds, and interbreed to produce poorly adapted progeny. (Beaumont, 2000; Gibbs, 2004). Genetic modeling of scallop culture indicates that hybridization may have severe effects on fecundity and overall fitness. Disease spread from the culture area to the surrounding ecosystem can have devastating effects

on native species (Stead et al., 2002). Furthermore, near shore aquaculture projects located in the vicinity of local shipping routes can have indirect negative effects on ecosystems, as it has been shown that ship ballast water is a vector for transferring exotic culture species (Beaumont, 2000). Careful site and species selection and proper management are necessities to anticipate and mitigate potential problems.

Economic Issues

A variety of economic factors need to be considered in LEAN development. Factors include the cost of land; energy and labor; access to clean seawater; the cost of supplies; marketing needs; product transportation; availability of educated and technically trained people; access to profitable markets; and political, business, and financial infrastructures that will support the aquaculture project.

Currently, most intensive aquaculture systems allow producers to externalize cost to the surrounding environment by discharging untreated effluent water free of charge and without regulation (Costa-Pierce, 2002a; Kaiser and Stead, 2002; Boyd, 2003; Neori et al., 2004). This situation has negative economic effects on polyculture or integrated systems (LEAN) that choose to internalize environmental costs by biofiltration. They are more sustainable, but often less efficient (Boyd, 2003; Neori et al., 2004). LEAN systems are disadvantaged in current market structures because production, management, maintenance, and marketing of them is often much more complex (Boyd, 2003; Cinner and Pollnac, 2004). However, speculation among scholars and individuals in the industry assumes that eventually “polluter pays” regulations will be imposed on many intensive aquaculture projects (Chopin et al., 2001; Boyd, 2003). This is already the case in locales such as Norway where aquaculture permits are based on site location, disease control methods, use of antibiotics and pesticides, interactions with other species, waste discharges and feed conversion ratios (Maroni, 2000). All of these criteria are also being considered in developing organic aquaculture certification standards in the United States (USDA, 2006). The results of such regulations could advantage more sustainable systems (Boyd and Clay, 1998; Naylor et al., 2000; Neori et al., 2004).

As with most development in rural areas, LEAN systems are faced with the challenge of generating revenue without creating social tensions caused by inequitable income distribution (Muir, 2005). On the other hand, many equity issues have been raised regarding failures of the aquaculture industry to distribute its wealth fairly. These issues are largely avoided by LEAN systems, which are often not owned by multinational corporations, or generate the vast amounts of wealth analogous with intensive systems, such as shrimp and salmon farms (Naylor et al., 2000; Hishamunda and Ridler, 2002; Muir, 2005). Historically, most LEAN systems are small, often localized, community-based, and common property. However, ensuring the equitable distribution of wealth as these systems develop remains a valid concern, especially given historical trends in economic development of the aquaculture industry. For example, two-thirds of the annual \$3.1 billion (all monetary values are presented in \$US) earned by the salmon and trout industry go to approximately 30 national and international companies (Naylor et al., 2000; Naylor and Burke, 2005).

One of the more obvious concerns associated with the development of LEAN is the lack of existing markets (Boyd and Clay, 1998; Muir, 2005). Since many potential and existing products are already being cultured successfully by other methods or in different locales, existing markets are saturated, of low value, inaccessible, or poorly researched (FAO, 2002). For example, seaweed is a low trophic level species that is of especially low-value; and yet it is undeniably necessary for many successful near shore, integrated and polyculture systems (Neori et al., 2004). While seaweed occupies a large market in parts of Asia, only small niche markets exist in the United States and Europe, both massive consumers of other seafood products (FAO, 2002). A similar situation exists for many of the species being considered for LEAN. For these types of culture systems to be successful, markets may have to be manufactured or created (Stead et al., 2002)—and the creation of markets requires a great deal of research and monetary investment (Muir, 2005).

In addition to finding or establishing markets, there are also obstacles in market chain development. While millions of potential consumers exist, in many cases there is no available infrastructure to process and distribute these products to consumers (FAO, 2002). In the central and southern provinces of Eastern China, where the most intensive freshwater aquaculture activities are situated, live fish is transported either to local markets or exported to Hong Kong by trucks equipped with compressors. In some places, lack of adequate refrigeration and transportation equipment may result in reduced quality and spoilage of products (NOAA, 2001). Other difficulties include the establishment of sales and marketing infrastructure, development of training for personnel, and development of price, health, and choice incentives for consumers (Gardiner and Viswanathan, 2004).

Finally, it is critical to note that the aquaculture industry has been plagued by an onslaught of bad publicity from environmental groups, academics, and the media in general (Naylor et al., 2000; Cinner and Pollnac, 2004; Naylor and Burke, 2005). More ecologically friendly systems could transform aquaculture's public image and provide a boon to the industry as a whole, creating a feedback system that could in-turn facilitate market development (Hishamunda and Ridler, 2002; Spaargaren and Martens, 2004). An issue that often goes unmentioned in the literature is the public perception and marketing of aquaculture (Muir, 2005). Muir (2005) states that aquaculture is now almost entirely market driven. He also states there is an increasing concern that aquatic products are properly sourced to avoid supporting ecologically and socially destructive culture practices. Consumers are highly aware of health issues that have been associated with farmed seafood products in the past. This is probably most notable in the case of farmed salmon. However, these sentiments have carried over to include any number of cultured products as well as LEAN culture systems. In the case of oysters grown near Venice, Italy, concerns about pollutants in oysters have brought considerable attention to the market, and concern is now the impetus for an eco-labeling campaign (Pellizzato and Da Ros, 2005). Even if local communities in developing countries are sufficiently interested in LEAN development, the stigmas associated with aquaculture as a whole must be overcome so consumers will differentiate between LEAN products and those produced by high impact, high trophic level, monoculture systems. The professional and academic aquaculture community, along with environmental organizations, need to help create more educated consumers of aquaculture products, such that LEAN products will become more socially acceptable in developed countries.

Social, Political, and Cultural Issues

There are numerous social, political, and cultural issues associated with the development of LEAN systems. The near shore of the ocean, relative to all other ocean regions, is by far the most accessible to people and the most ecologically productive. Thus, the near shore is often a culturally and historically significant source of food, income and recreation for many people (GESAMP, 2001a; GESAMP, 2001b). Approximately 37% of the global population, over 2 billion people, lives within 100 km (60 miles) of a coastline, 44% live within 150 km, and 49% within 200 km (Cohen et al., 1997). Additionally, except in the most rural areas, there is often a multitude of stakeholder interests to consider with any new or changing development in the near shore zone (Gilman, 2002).

An apparent obstacle to efficient and widespread operation of LEAN systems is that in many developing countries there is a lack of adequate educational infrastructure to train required labor (Stead et al., 2002; Tarifeno-Silva, 2002; Wescott, 2002). This has been the problem in the United States Affiliate Islands where repeated efforts to establish giant clam and other culture systems have been unsuccessful. Because culturing organisms in the near shore can be a complex endeavor, the ability to educate and train workers is vital. The lack of educational opportunities can result from several factors: the inability to pay competitive wages; few incentives to attract already trained people; a dearth of specialized higher education programs focused on aquaculture; language and cultural barriers; and a paucity of established training programs associated with an emerging field (Boyd and Clay, 1998; Muir, 2005).

In particular, training to familiarize potential farmers with production systems, techniques and species, and to introduce farmers to well-trained academics and professionals is necessary during the initial stages of LEAN development (Hishamunda and Ridler, 2002). In most cases the long term viability of LEAN systems also requires intermittent consultation and continued training to deal with technical issues that may include disease remediation, new technologies, marketing and infrastructure development (Wescott, 2002; Jana and Jana, 2003). Such training programs can be especially difficult to implement in developing nations where long-term collaborative education and support programs often require cooperative arrangements with developed nations.

Often, LEAN development may conflict with other social and economic uses of the near shore. In many areas proposed or suitable for LEAN development, tourism and recreation play vital social and economic roles (Foster and Haward, 2003). Multi-stakeholder management techniques, such as integrated coastal zone management and collaborative processes, have been proposed (GESAMP, 2001a; GESAMP, 2001b) and are being used as a framework with which to address some of these conflicts in Tabasco, Mexico where fishermen's perceptions of aquaculture development are being shaped by the restructuring of fishermen's groups and the establishment of formal and informal organizations (Perez-Sanchez and Muir, 2003; Muir, 2005).

User conflicts regarding near shore management also include those related to cultural and historical use of the near shore. Successful near shore aquaculture development in other regions of the world, such as Southern Australia or Alaska, requires a cogent understanding of existing native cultures and their relationship with the near shore region (Lee and Nel, 2001; Harvey and Clarke, 2002). The Alaska National Interest Lands Conservation Act (ANILCA) of 1980 gives explicit priority to rural residents to utilize fish and wildlife for subsistence. Thus, in the event that herring roe harvests are limited, subsistence users would be granted priority over commercial interests.

Coinciding with an understanding of the cultural use of the near shore is an ability to develop LEAN systems in which the specific labor requirements are amenable to the local community or labor force. This has been shown to be very difficult in areas with specific gender roles (Muir, 2005). On the other hand, some communities have been more flexible and eager to adopt new roles as part of LEAN projects. In Bandon Bay, Thailand, the encouragement of people to establish cockle farms serving as nursery grounds for aquatic organisms was considered a top priority by fishermen and other coastal stakeholders (Jarernpornnipat et al., 2003).

Conflicts involving local perceptions of natural resource use are also important to consider. In Baja California, for example, it has been very difficult to overcome the local opposition of coastal fishers to near shore aquaculture systems (Cinner and Pollnac, 2004). Local fishers think that aquaculture operations will reap all of the profit, while local fishers will do worse economically. This has also been the case in varying degrees in British Columbia, Alaska, Australia and Mexico (Gilman, 2002; Crawford, 2003; Cinner and Pollnac, 2004), where fishermen have opposed or complicated the development of culture systems for fear of compromising their fishing grounds, markets or operational capacity.

Social conflicts also can arise because traditional farmers feel threatened by the success of commercial aquaculture, and because of concerns that aquaculture development will cause environmental damage (Hishamunda and Ridler, 2002; Jarernpornnipat et al., 2003; Cinner and Pollnac, 2004). Sometimes existing aquaculture farmers are opposed to aquaculture development in the near shore, as they worry about additional competition. This was the case in Bandon Bay, where shellfish farmers formed alliances to oppose the establishment of shrimp farmers who would likely garner more profits from their exploits (Jarernpornnipat et al., 2003). Further exacerbating this problem, shellfish farmers often require large loans to become established in the area.

In locations where there is not buy-in from local communities, LEAN may not be worth pursuing. On the other hand, in developing countries especially, many perceive aquaculture to be a money-making endeavor; thus community interest in LEAN development may be strong—particularly in areas with faltering tourism industries or declining capture fisheries (Perez-Sanchez and Muir, 2003).

Political factors also will influence the relative economic, social, cultural, and ecological success of LEAN development. A multitude of national, state, and local governments—as well as international governing bodies—are currently involved in near shore aquaculture development to different extents. The involvement of official governing bodies, or lack thereof, can be a considerable concern in LEAN development. In any particular country, tax incentives, low interest loans, training, infrastructure development, and market support for aquaculture may all fall under the purview of different government entities, making coordinated aquaculture development difficult. Moreover, because ecosystems do not recognize political boundaries, LEAN development will in many cases require coordination both between local and national governments, as well as between different nations. Governments also play a crucial role in forming and implementing regulations as they pertain to LEAN development. For these reasons, the absence of proper government leadership can be an insurmountable barrier to successful LEAN development.

CONCLUSION

The breadth of the recommendations made here is indicative of the enormous gaps in the literature regarding low trophic level near shore aquaculture. As described in the integrated mangrove-shrimp case study, basic information about near shore ecosystem functioning is absent in the literature, making assessment of LEAN's impact on near shore ecosystems difficult. Additionally, current understanding of market development for LEAN products is also limited. In some cases, such as with the herring spawn-on-kelp system, a market is easily identified and accessed. In other cases, such as with the giant clam species that need to be transported alive from the South Pacific to Japan, markets are conditional in a way that makes accessing them difficult. Moreover, as seen in the giant clam case study, the cultural acceptability of LEAN practices seems largely site-specific and dependent upon a variety of sociological, cultural, political, and economic factors.

Overall, the research needs as they relate to LEAN development are immense. Given the scale of research needs at this time, ACRSP's efforts are best focused on, 1) identifying existing LEAN systems that could be supported or studied as is, and on 2) identifying current fishing and aquatic management practices that could be easily developed into LEAN systems. In both cases, ACRSP should only fund research of sites where local markets exist or are easily accessed, where LEAN practices would be readily accepted by local communities, and where local communities are open to interdisciplinary study of local economic, ecological, and cultural systems and structures.

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FARMERS TRAINING IN TANZANIA

Twelfth Work Plan, Economic/Risk Assessment & Social Impacts 3 (12ERA3)

Final Report

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INTRODUCTION

Subsistence private fish ponds, also called farm ponds, dominate fresh water systems of fish culture activities in Tanzania. Depending on weather, fish farming potential availabilities and human resource capital investment, many new ponds continue to be constructed each year. While most ponds are found in the six most potential regions - Arusha, Kilimanjaro, Morogoro, Iringa, Mbeya and Ruvuma, fish ponds are almost widely distributed throughout the country. While fish ponds provide many important and practical benefits such as erosion control, fire control, livestock watering, irrigation, swimming, picnicking and wildlife enhancement, produce from fish pond is found to provide animal protein and income to households. The Tanzania ruling party manifesto and the policy of 'poverty reduction and economic recovery' have put much emphasis on aquaculture development and improvement in the country. However, good fish farming doesn't just happen. It's the result of intensive extension delivery and formal and informal farmers training that gears into appropriate pond site selection, good pond engineering practices, quality fingerling supplies and proper fish management. Managing the fishpond wisely, results in high pond production, and this can be done with little additional investment if a proper knowledge is imparted into a farmer.

Tanzania has an area of 942,600 km², 6.55% of its area is open waters (615,000 km²). Fish harvested in Tanzania is about 350,000 tones, which is far short of the country's capacity of 750,000 tones. A large amount of fish produced in the country is locally consumed, with the exception of Nile Perch, shrimps and sardines, which are exported. For the past five years the fisheries sector has been contributing 1.6% to 3.1% to the country's economy. Based on the estimated annual consumption of fish of 15kg/head, the projected demand for fish was set at 368,878 tones in 1990; however capture fisheries produced only 359,000 tones, leaving a deficit of 9,873 tones, which were expected to come from aquaculture. However, 1989 data shows that aquaculture produced only 375 tones.

Currently, the aquaculture industry is dominated by smallholder farmers. However, aquaculture must compete with other rural industries for land, water, labor and nutrients. This calls for deliberate efforts to evaluate the costs and benefits of aquaculture and its contribution to rural livelihood versus other industries. However, aquaculture is also faced with many problems and challenges including absence of a concrete policy for aquaculture; changes in economic policies; lack of appropriate technologies; lack of improved fingerlings; poor transport infrastructure; inadequate research; lack of production records/statistics; inadequate appropriate information management. In order to be able to operate any enterprise, it is important to have complete records of the performance of the enterprise. Similarly, to operate a farming enterprise, the owner needs to have clear and complete records of all the operations carried out on the farm including records of all cash receipts and expenditures.

There are fewer number of fisheries professional and personnel employed in all levels of government, from District to the national. Fish farming extension services are tremendously inadequate. However, the Fisheries Division has been organizing pond site training for farmers with the aim of imparting fish farming technological and development to farmers. The first phase of this study, which was a survey, revealed that, among others, record keeping was one of the limiting factors for the development of aquaculture in the country. It was found that almost all farmers do not keep written records that can be useful for statistical analysis, hence the importance of organizing and conducting fish farmers training. By keeping records of their aquaculture activities, farmers can be in position to solicit financial support from financial institutions. It is anticipated that such records would prove useful for purposes of decision-making.

OBJECTIVES

1. To provide training on pond management, fish feed and fish health management.
2. To teach farmers principles and benefits of record keeping.
3. To teach farmers simple methods for assessing and evaluating costs and benefits.

MATERIALS AND METHODS

The Training workshop involved 24 existing fish farmers from three Morogoro region districts (Mahenge – Ulanga, Kilosa and Mvomero) and one farmer was from Mwangi district in Kilimanjaro region. Three Fisheries professional from each District also attended the training with the aim of making them aware and be able to advise properly when a farmers seeks their assistance. The training was held from June 18th through 22nd 2007 at the Institute of Continuing Education Conference Hall of the Sokoine University of Agriculture. The training sessions focused on general pond construction engineering, working equipments, pond management, pond fertilization and live food production in the pond, hatchery and pond management, artificial cat fish reproduction, fish enemies and fish diseases and their control, fish farming activity record taking and keeping. Teaching modules were developed by resource persons from University of Arkansas at Pine Bluff, USA; Fisheries and Aquaculture Division - Tanzania, and the Department of Animal Science - Sokoine University of Agriculture. Teaching materials for Moi University were also used for the training. Farmers were selected on the basis of their levels of fish farming experience, awareness and willingness to educate fellow neighbors. However, a farmer from Mwangi district in Kilimanjaro region was allowed to attend after a special request from the Fisheries Division in that area because they haven't received any training on fish farming although they are practicing it. Fish farmers trained comprised of both male and female farmers. The training utilized techniques such as illustrations, open discussions, sharing of experiences, and questions and answers. There were also some practical hands-on sessions that involved catfish artificial breeding, catfish and tilapia sex identification, and fertilizing ponds using poultry manure. Farmers also had some laboratory experience examining microorganisms from pond water under a microscope. Teaching resources used included power point presentation of developed modules using LCD projector, projector, flipcharts, posters and handouts. The medium of instruction was Kiswahili because all farmers understood and were able to communicate very

well in Kiswahili as it is the national language. Trainees also visited the ponds and hatchery site at Kingolwila Fish Center. Details of day to day activities are presented in the program in the Appendix.

RESULTS

Generally, the training was successful. The teaching modules were presented in the most basic form in Kiswahili. Topics taught include pond construction, pond management, hatchery management, introduction to commercial fish farming, potential problems in commercial fish farming, record keeping, and artificial propagation of catfish. Farmers engaged in open discussions, where many shared their fish farming experience freely. This session was quite lively and brought out technological deficiencies in current farming methods.

Study topics were translated into Kiswahili, and hard copy printed for handout distribution to farmers. The handouts will be good reference materials for the farmers. Questions, comments and ideas presented by farmers and resource persons were written on flip charts to enable slow writing farmers to copy.

Evaluation Questionnaire

An evaluation questionnaire was administered to the participants at the end of the program. The complete analysis is available in the appendix. Catfish artificial reproduction and record keeping were rated the most important issues learned, but when asked where changes would be made in their operations, most spoke about improvements in hatchery and pond management. When asked about new management techniques learned, most indicated areas in pond management or hatchery management. Most farmers indicated while they are back to their destinations, they are going to make changes in their habit of managing ponds and even try to breed catfish. About a third indicated they learned new record keeping techniques.

DISCUSSION

The farmers appreciated this training very much because, although they have been attending many formal and informal training on fish farming, this one gave them much technological knowledge and hands-on practice on things that will help them improve their fish operations. Farmers shared their experiences on common fish farming problems and what solutions were adopted. Surprisingly, some farmers had cell phones so there were exchanges of phone numbers among farmers and Fisheries personnel to enable contacts and response to any technical questions or issues whenever they arise.

Farmers were amazed to learn that keeping good farm records could open doors to banks, financial institutions and government agricultural lending agencies for business loans. The Kenyan experiences were shared with farmers. Farmers were encouraged to form Social Community Credit Savings (SACCOS) arrangements to make them stronger with one voice when they are presenting their issues to the government.

ANTICIPATED BENEFITS

From this training, fish farmers can start keeping farm records that would be useful for securing loans from financial institutions, including government lending agencies. Farmers can also manage their farms better and potentially increase yield and therefore revenues. With knowledge of spawning catfish, farmers can make additional income by hatching their own catfish and also selling some to other farmers. When the knowledge acquired from the training is put into use, farmers stand a good chance of improving their livelihood by moving from subsistence fish farming to commercial fish farming. Financial institutions will also be better informed about the economic viability and the relative profitability of the fish farming business compared to other traditional agricultural enterprises. The fish farming business will then be in a position to obtain the needed financial assistance for investment in the industry. An economically viable

aquaculture industry will also attract additional government resources and services such as extension.

RESOURCE PERSONS

S/N	Name	Gender	Institution s/he comes from
1	KAJITANUS OSEWE	M	KINGOLWILA FFC, FISHERIES DIVISION
2	RITHA MALY	F	FISHERIES DIVISION HEADQUARTER
3	CHARLES NGUGI	M	MOI UNIVERSITY-KENYA
4	JAMES MUGO	M	MOI UNIVERSITY - KENYA
5	EPHRAIM SENKONDO	M	SOKOINE UNIVERSITY OF AGRICULTURE
6	BENNO MNEMBUKA	M	SOKOINE UNIVERSITY OF AGRICULTURE
7	YOVITA MALLY	F	KINGOLWIRA FFC, FISHERIES DIVISION
8	REGINA NZEYAKUSANGA	F	MBEGANI FISHERIES DEVELOPMENT CENTER

LIST OF PARTICIPANTS NAMES OF PARTICIPATING FARMERS

	Name	Gender	Age	Village	District
1	Ibrahim Selemani	Male	67	Mkindo	Morogoro
2	Charles Mgoda	Male	30	Kilosa	Morogoro
3	Pancras Kaanyali	Male	41	Mahenge	Morogoro
4	Bernard Chande	Male	69	Mgeta	Morogoro
5	Jovin Damian	Female	46	Mgeta	Morogoro
6	Fatuma Mbano	Female	48	Mkindo	Morogoro
7	Mwanaidi Hamza	Female	30	Mkindo	Morogoro
8	Elizabet Mboma	Female	58	Kilosa	Kilosa
9	Melania Musa	Female	40	Isongo	Mahenge
10	Costantine Mhulo	Male	65	Mgeta	Mvomero
11	Mohamed Mustafa	Male	41	Mkindo	Mvomero
12	Ruphino Soli	Female	39	Makanga	Mahenge
13	Conrad Kipila	Male	65	Mgeta	Mvomero
14	Hamisi Funge	Male	54	Mkindo	Mvomero
15	Damian Liambiko	Male	61	Ulanga	Mahenge
16	Athanas Madumula	Male	33	Kituti	Mahenge
17	Benedict Mizambwa	Male	60	Mgeta	Mvomero
18	Costansia Raphael	Female	48	Vidunda	Kilosa
19	Getrude Joseph	Female	43	Mgeta	Mvomero
20	Mohamed Mkwizu	Male	35	Kivulini	Mwanga
21	Wiliam Chambua	Male	52	Morogoro	Morogoro
22	Selemani Sadiq	Male	20	Mkindo	Mvomero
23	Musa Kibwinamoto	Male	48	Mkindo	Mvomero
24	Ignatus Mkude	Male	68	Mgeta	Mvomero
25	Issa Makuo	Male	20	Mkindo	Mvomero
26	Anastasia Mgendera	Female	46	Isongo	Mahenge
27	Ole Mungaya	Male	30	Mahenge	Mahenge

NB: the bolded names are district fisheries officers in the respective districts

PROGRAMME FOR THE FISH FARMERS TRAINING SCHEDULE FROM 18TH JUNE TO 22ND JUNE 2007 AT INSTITUTE OF CONTINUING EDUCATION – SOKOINE UNIVERSITY OF AGRICULTURE

Date: June 17, 2007 (evening): Arrival of participants

Date: June 18, 2007

Time	Event	Responsible	Indicator
08.30 – 09.30	Registration/breakfast	All	Names & sign of the participants
09.30 – 11.00	Pond construction engineering; insisting on the use of available domestic equipment available	Dr. Mnembuka	Concept gained for future practices
11.00 – 11.30	Tea – Coffee	All	Participation
11.30 – 11.30	Introduction on commercial fish farming	Dr. Ngugi	Concept gained for future practices
11.30 – 01.20	Introduction to Cat fish farming; insisting on available opportunities, conducive weather, possibilities of breeding catfish breeding and availability of market for bait in Lake Victoria	Dr Ngugi Mr. Osewe	Concept gained for future practices
01:20 – 02:00	Lunch	All	Participation
02.00 – 07.00	Discussion and feedback/Field excursion to Kingorwila Fish Farming Center to visualize earthen ponds, catfish hatchlings and tilapia and catfish sex identification	Mr. Osewe Dr. Ngugi	Participation of everyone

Date: June 19, 2007

Time	Event	Responsible	Indicator
07.30 – 08.30	Registration/breakfast	All	Names & sign of the participants
08.30 – 11.30	Artificial cat fish breeding practical experiment on artificial propagation, hatchery management, Nursery pond preparation	Dr. Ngugi Mr. Mugo Mr. Osewe	Concept gained for future practices
11.30 – 12.00	Tea – Coffee	All	Participation
12.30 – 01.00	Importance of group formation and working on cluster	Dr. Ngugi	Concept gained for future practices
01.00 – 02.00	Introduction on Fish Farming Record taking and keeping	Dr. Ngugi	Concept gained for future practices
02.00 – 02.45	Lunch	All	Participation of everyone
04.00	Recapitulating the lessons already given for open discussions	Dr. Ngugi, Mr. Osewe, Ms Maly & Mr Mugo	Concept gained for future practices

Date: June 20, 2007

Time	Event	Responsible	Indicator
07.30 – 08.30	Registration/breakfast	All	Concept gained for future practices
08.30 – 09.00	Assistant Director of Fisheries Training remarks from The Director	Mr Moreni	Delivery of the Fisheries policy and Government vision upon Fish Farming
09.00 –10.30	Fish farming Economics and record taking and keeping.	Dr Senkondo	Concept gained for future practices
10.30-11.00	Tea break	All	Participation
11.00 –12.30	Importance and type of records, collaboration between fish farmers and researchers on record keeping	Dr Senkondo	Concept gained for future practices
12.30–01.15	Lunch	All	Participation
01.15–04.30	Farmers participation on cat fish artificial propagation at Kingolwira	Mr. Osewe	Concept gained for future practices
07.00 – 10.00	Welcome dinner	All	Participation of every body

Date: June 21, 2007

Time	Event	Responsible	Indicator
07.30 – 08.30	Registration/breakfast	All	Names & sign of the participants
08.30 – 10.00	Tilapia culture: insisting on integrated farming system	Ms. Mally	Concept gained for future practices
10.00 – 10.30	Tea – Coffee	All	Participation
10.30 – 12.30	Tilapia culture: Quality fingerlings production and management	Mr. Osewe	Concept gained for future practices
12.30 – 02.00	Lunch	All	
02.00 – 05.00	Trip to Kingolwira for fry fish live food production and managing the cat fish hatchlings	Mr. Osewe	Concept gained for future practices

Date: June 22, 2007

Time	Event	Responsible	Indicator
07.30 – 08.30	Registration/breakfast	All	Names & sign of the participants
08.30 – 10.00	Common Fish enemies in the area and means of controlling them	Ms. Mally	Concept gained for future practices
10.00 – 10.30	Tea – Coffee	All	Participation
10.30 – 12.30	Common fish pathogens and means of treating them	Ms. Nzeyakusanga	Concept gained for future practices
12.30 – 02.00	Lunch	All	Participation of every body
02.00 – 04.30	Kingolwira trip for checking the development of the cat fish hatchlings and feeding them with artemia	Mr. Osewe	Concept gained for future practices
03.30 – 07.00	Exercises/ discussion, feedback recapitulation and evaluation of the training	All	Question and answer notes and filled evaluation forms

Date: June 23, 2007 (Morning) Departure of participants.

**AN EX ANTE ASSESSMENT OF COASTAL AND MARINE AQUACULTURE DEVELOPMENT: CHARTING
COMPARATIVE STRENGTHS AND WEAKNESSES OF LOW TROPHIC SPECIES FOR OFFSHORE
AQUACULTURE IN DEVELOPED AND DEVELOPING COUNTRIES**

*Twelfth Work Plan, Economic/Risk Assessment & Social Impacts 5 (12ERA5)
Final Report
Published as Submitted by Contributing Authors*

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ABSTRACT

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

1. INTRODUCTION

1.1 Outline

This report assesses the ex ante aquaculture potential for low trophic level aquatic species in exposed, high-energy ocean environments with an emphasis on developing countries. This form of aquaculture is also commonly designated as “offshore” or “open ocean aquaculture”. This review draws from coastal and nascent offshore aquaculture applications in developed and developing countries. We analyze likely candidate species and then draw in other attendant factors crucial for sustainable development.

The principle objectives of this study were to:

- Identify the biological, production and market strengths and weaknesses of low-trophic species in offshore aquaculture from a sustainable development framework.
- Address key social variables such as; potential conflicts with other user groups, organizational capacity, property and property rights, and economic impacts.
- Determine the overall benefits and costs to producing countries in both the developed and developing world.

To attain the above objectives, this study will:

- Conduct case studies of offshore aquaculture development
- Conduct interviews with authorities on offshore aquaculture development.
- Review relevant scientific and governmental literature.
- Collate existing data on worldwide offshore aquaculture development.

- Identify and assess low-trophic species with offshore aquaculture potential, with a focus on the developing world.

The study will provide:

- A case-by-case assessment of the strengths and weaknesses of a number of low-trophic species to determine suitability for exposed ocean culture.
- Evaluation of expected social and economic effects
- Prognoses on the viability of offshore culture of low-trophic species, with a focus on developing countries.
- A synopsis of the case studies

1.2 Background

In recent years Open Ocean Aquaculture (OOA) has become widely recognized as a significant area of marine development.¹ The idea of utilizing the exposed ocean environment for aquaculture has been discussed for the last 35 years. The first organized investigation into utilizing the open ocean for aquaculture occurred in 1970 when a National Oceanic and Atmospheric Administration (NOAA) grant brought together systems engineers, oceanographers and marine biologists who took a remarkably holistic approach in exploring the feasibility of what was considered a very futuristic activity (Hanson 1974). More recently, open ocean aquaculture operations have emerged in a growing number of countries around the world. In most of the developed world, OOA represents a technical progression from the existing near shore net-pen culture of salmonids and other aquatic species in sheltered coastal areas. The industry-need to move operations further offshore is due to requirements for expansion, access to clean water, and avoidance of some of the user conflicts encountered by aquaculture in near shore areas (Bridger and Neal 2004). User conflicts in the US, Canada, Scotland, and Ireland where groups such as property owners, recreational boaters, anglers, fishers and environmental organisations increasingly object to the siting of facilities (Belton et al 2004).

Spurred on by entrepreneurs, academics and governmental agencies, the move to grow aquatic organisms in exposed marine environments has generated professional and entrepreneurial networks and increasingly -- public attention. Many exposed operations however, are of an experimental or limited commercial scale, often close to shore. Nevertheless, evidence suggests that some quasi-offshore aquaculture (e.g. tuna ranching) can be both commercially viable and extremely profitable (Dalton 2004). The environmental impacts associated with bluefin tuna ranching however, were recently raised by Dalton (2004) over viral disease transference from imported sardines used as tuna feed and sea lion slaughter. Volpe (2005) also questions the overall sustainability of this industry. In regards to low trophic species, more specifically blue mussel culture from New England meets low trophic requirements that guide this report (UNH <http://www.ooa.unh.edu>). Other development schemes e.g., stock enhancement, fishing-aquaculture, artificial reefs-aquaculture, and integration schemes (e.g., Langan 2004) have also drawn some interest. Oil platforms have also been identified as potential growing sites, including use as depuration sites for Gulf shellfish (Louisiana Department of Natural Resources 2005). At this juncture many schemes are speculative in nature and a somewhat fragmented patchwork of ventures is beginning to unfold across many parts of the world (See Table 2, page 9).

In the developing world, OOA seems to be emerging in countries with longer traditions of aquaculture. Thailand, for example, has recently announced an ambitious water permit system encouraging fishermen to take up the culture of finfish and shellfish, some of which may occur at exposed ocean sites. It remains to be seen whether this scheme becomes a reality. Taiwan, Vietnam, and especially China also have interests in developing offshore aquaculture. Some

¹ Open Ocean Aquaculture and offshore aquaculture are synonymous terms. A definition is supplied by CRS (2004:1) that states open ocean aquaculture as "the rearing of marine organisms under controlled conditions in exposed, high-energy ocean environments beyond significant coastal influence." We characterize low trophic organisms as those possessing a trophic level of around or less than 2.0 at maturity. This definition allows for the inclusion of several fish species (www.fishbase.org).

commentators have suggested that the next phase of offshore aquaculture development may accelerate in developing countries due to market dynamics and by implication less stringent environmental regulations, infrastructure and low labor costs (CRS 2004).

In general, the aquaculture of low trophic level marine organisms in offshore marine environments has not yet occurred on any substantial commercial scale anywhere in the world. Exceptions are found however, in Eastern Canada and Ireland where mussels have been reared in semi-exposed high energy ocean conditions for decades (Personal Comm. Informant 18). There are substantial efforts underway to raise salmon at exposed ocean sites in New Brunswick (Bridger and Neal 2004), and research from New Hampshire shows viability with commercial blue mussel culture undertaken by fishers (<http://www.oaa.unh.edu>). While the concept may hold promise in certain situations, *our major finding indicates that in the case of developing countries offshore cultivation of low-trophic species for food, pharmaceutical; bioremediation and industrial purposes will encounter a number of obstacles that severely restrict development options.* These obstacles include:

- Overcoming extreme physical limitations posed by the environment
- Meeting biological-culture requirements of candidate species
- Designing economically viable and competitive culture systems
- Achieving viable economies of size and scale
- Making sense of traditional marine tenure, common property systems, regulatory jurisdictions, permits, leases and property rights
- Conforming to environmental, health and commodity standards
- Contributing to coastal community development and avoiding user conflicts, environmental problems and public opposition

An extensive review of literature and a number of interviews with key informants in this field revealed that at present high value trophic level finfish culture for luxury markets dominates virtually all research and development efforts. This is so because all of these offshore projects will involve over considerable time, comparatively large fixed and variable costs and investment in order to overcome the difficulties associated with working in high-energy exposed ocean environments. Because of the necessity of minimizing these costs, it is likely that developing countries in Asia will ultimately emerge as leading finfish exporters, and that operations will be large in scale and run by corporate entities with adequate financing resources over the long run.

At present, Northern developed countries are actively embarking on advancing technical capacity through production-oriented research, development and demonstration projects. In the United States a major Federal government regulatory policy framework is emerging and in Ireland an international offshore aquaculture R&D center has been proposed. However, we anticipate that offshore aquaculture development in the United States will be complicated by a daunting set of legal and regulatory hurdles, conflicts between different agency jurisdictions and by opposition from some fishing and environmental groups. Other countries (e.g., Canada through Federal-Provincial integration initiatives) may not find this regulatory hurdle as burdensome. Investment capital is likely to be limited or viewed as a high-risk venture. These obstacles, even if temporary, increase capital and operating costs thereby making developing countries more attractive for investment. We also anticipate that technology transfer from the North to the South will spur the development of offshore marine systems, most notably finfish culture, in developing areas.

As one of our informants noted, there are major gaps in our knowledge of oceanic environments. While the open ocean is considered a relatively stable environment concerted ocean mapping exercises are likely to reveal further valuable information on suitable offshore culture areas in the future. At present, *optimum* sites for exposed ocean aquaculture operations are only partially identified. Regardless of where offshore aquaculture unfolds, inherently high capital and operating costs and risk will pose severe obstacles to more speculative or ill-conceived offshore projects.

Overall, we encountered some skepticism by the majority of informants on the prospects of farming low trophic species in exposed ocean sites. However, given the scant interest in this particular form of offshore aquaculture to date, these opinions were perhaps unsurprising. In this report we assess those low trophic candidate species and possible development scenarios that may warrant further investigation, exploring possibilities for the offshore culture of:

- Pearl oysters
- Sponges
- Giant clams
- Trochus
- Abalone
- Seaweeds
- Mussels and other bivalves
- Low-trophic finfish
- Sea urchins and sea cucumbers

In envisioning some development scenarios we cannot overemphasize enough, as a preliminary step, the critical importance of an environmentally rigorous and thorough site selection. This process should also include assessment of the social and economic dimensions of these development activities that, in our view, have not yet received sufficient attention.

1.3 A Definition of Offshore Aquaculture

In the USA, offshore aquaculture is defined as the; *“rearing of marine organisms under controlled conditions in the EEZ – from the three mile territorial limit of the coast to two hundred miles offshore. Facilities may be floating (for example, net pens for rearing of finfish and rafts from which strings of mollusks are suspended), submerged (fully enclosed net pens or cages moored beneath the water surface), or attached to fixed structure”* (Stickney, 1994).

This definition, whilst providing a useful and accurate description of offshore culture methods, is of limited scope as it defines offshore aquaculture in legal and territorial terms as being located only in the Exclusive Economic Zone (EEZ). The Irish Sea Fisheries Board (BIM) has adopted a classification based on the physical environment and corresponding finfish cage structure. This study will adopt BIM’s more universal classification. Table 1 below summarizes the classification system.

Table 1. A Classification System of Marine Aquaculture Sites

Class	1	2	3	4
Description of Site Exposure	Sheltered Inshore Site	Semi-exposed Inshore Site	Exposed Offshore Site	Open Ocean Offshore Site
Cage Type Used	Surface gravity	Surface gravity	Surface gravity, Anchor Tension	Surface gravity, Surface Rigid, Anchor Tension, Submerged

As one moves from class 1 to class 4 sites wave energy increases, requiring a corresponding increase in the sophistication of cage technology, feeder and work boats (Ryan, 2004). Conventional coastal finfish aquaculture (e.g., salmon) takes place in class 1 and 2 sites. However, as category 3 and 4 sites become developed, experimental cage technology is required to cope with the exposed physical environment. For the purposes of this study, any class 3 or class 4 site, i.e. one exposed to any significant degree of high-energy wave action, is considered offshore, regardless of its proximity to land.

2. A SUMMARY OF OFFSHORE AQUACULTURE AROUND THE WORLD

2.1 Geographical Distribution

Table 2 shows that the vast majority of offshore aquaculture around the globe entails the culture of high trophic level finfish destined for high-end markets. There are few known instances of commercial offshore production of low trophic species and these are limited to shellfish. At present there is very little if any significant commercial finfish production occurring in the most highly exposed (category 3 and 4) offshore sites.

The Mediterranean, Ireland, Australia and New Zealand are major loci for offshore aquaculture development. In addition to ranching tuna, the Mediterranean region produces large quantities of seabass (*Dicentrarchus labrax*) and several varieties of seabream, primarily *Sparus aurata*. Ireland and Canada are involved with developing offshore salmon and existent mussel culture. Australia and New Zealand are engaged in mussel culture with other high trophic finfish culture systems emerging. Countries on the Eastern Pacific rim, particularly Taiwan, have closed the lifecycles of numerous tropical and subtropical Pacific species, but commercial offshore production of these has yet to take place on any major scale. Japan has closed the life cycle of bluefin tuna, and the fisheries laboratory at Kinki University's Oshima station now operates a commercial venture from egg to store (Wray 2005). Norway has also closed the lifecycle of a number of North Atlantic species, but has not yet found it advantageous to enter into offshore production. The USA is perhaps the world leader in offshore aquaculture in terms of diversity, and is developing legislation that will enable fish farms to operate 3-200 miles from its coastline in the Exclusive Economic Zone.

2.2 Global Development

Offshore aquaculture in developed countries has focused almost exclusively on the production of high value finfish species with some mussel and pearl culture. This growth has been enabled by the existence of a network consisting of scientific and bureaucratic infrastructure and expertise, and public and private investment capital. Asian countries that have historically practiced aquaculture and possess existing expertise and infrastructure are beginning offshore development for both domestic and export purposes.

Non-Asian developing countries with proximity to prime markets may begin to move offshore as technology transfer occurs. We surmise that this development will be stimulated by foreign investment (e.g. joint-ventures) from countries with advanced technology, and by the work of aquaculture consultants based in these countries. This supposition appears to be born out in the case of countries such as Panama and Mexico where production of tuna has occurred through joint venture arrangements, subsequent to advances made in developed countries (Dalton 2004). Aranda and Cardenas (2002, p47) provides a similar overall assessment, stating that, "countries with an aquaculture tradition have supported its development and modernization with research, while countries where aquaculture is a relatively new activity have generally limited their efforts to the introduction of production technologies developed elsewhere."

3. CASE STUDIES²

In the course of our research we conducted two case studies of offshore aquaculture development in the United States. These were carried out in order to redress the scarcity of concrete information on the social and economic aspects of such development. In closely studying the conditions that influenced and facilitated offshore finfish and blue mussel aquaculture in its early stages, and in examining the potential effects, we aimed to draw findings applicable to offshore aquaculture development across the globe in its many forms.

² See appendices 1 & 2 for the complete case studies

Table 2. Location and Status of Offshore Aquaculture Around the World.

LOCATION	SPECIES	STATUS	COMMENTS
Global			
Australia	Tuna	C	10,000 mt/year, value Aus\$250million*
Canada	Cod, Sablefish, Mussels, Salmon	N/A	Strategy under development* Mussels well established in Eastern Canada, some sablefish permits in BC.
Canary Islands	Seabass, Seabream	N/A	2 cages installed, no longer in use*
Faeroe Islands	Unknown	N/A	Trials in exposed sites unsuccessful*
Germany	Seaweed, Mussels	E	Integrated trials attached to wind-farms****
Ireland	Atlantic salmon	E	Various experimental projects*
Mexico	Tuna	C	###
New Zealand	Mussels		Industry preparing to go offshore*****
Panama	Tuna	C	###
Puerto Rico	Cobia, Snapper Spp	C	Commercial production of cobia underway* (Incomplete data, current production higher)
Mediterranean			
Croatia	Tuna	C	8 o/s cages in 1998 for seabass & seabream #
Cyprus	Seabass, Seabream	C	8 o/s cages in 1998 for seabass & seabream #
France	Seabass, Seabream	C	13 o/s cages in 1998 for seabass * seabream #
Greece	Seabass, Seabream	C	*
Italy	Seabass, Seabream, Tuna	C	#
Malta	Seabass, Seabream, Tuna	C	3 o/s cages in 1998 for seabass & seabream #
Morocco	Tuna	C	#
Spain	Seabass, Seabream, Tuna	C	Government assisted trials in class 3-4 sites*
Turkey	Seabass, Seabream	C	*
USA			
California	Striped bass, California yellowtail, Pacific Halibut, Abalone	E/C	Application to begin production on an oil platform underway**
Hawaii	Kahala, Moi	C	Kahala = Amberjack, Moi = Pacific threadfin**
New Hampshire	Cod, Haddock, Atlantic Halibut, Summer Flounder, Mussels, Sea Scallops	E/C	Demonstration project at the University of New Hampshire**, 2 sites for commercial application of mussels####
Washington	Sablefish	C	Attempts to establish o/s industry underway
WESTERN PACIFIC			
China	Unknown Finfish, Scallops	E	Small scale experimental finfish projects*, ####
Japan	Tuna, Mussels	C	Commercial tuna ranching###. Reports of offshore mussel long-lines, status unknown*****
Korea	Scallops	?	#####
Taiwan	Cobia	C	3,000mt in 2001##

2 E = Experimental or demonstration project ; C = Commercial production

Sources : * Ryan (2004) ; ** Belton et al. (2004) ; *** Eckachai (2004) ; **** AWI (2004) ; ***** Jeffs (2003) ; # CIHEAM (2000) ; ## Liao et al. (2004) ; ### ANTF (2002) ; #### UNH <http://www.oa.unh.edu> ; ##### Personal Comm. Informant 16.

The studies took place in Hawaii, widely regarded as at the forefront of offshore aquaculture in the Pacific US, and in New England, where development of an offshore aquaculture project has resulted in commercial offshore blue mussel culture. We found that in both instances offshore aquaculture was envisaged as a way to diversify depressed rural economies suffering from the decline of resource based industries. In Hawaii, outside of general statements calling for the need

to create more jobs, little concrete assessment exists that further quantifies or clarifies these claims. In New England, near shore commercial fishermen cooperatives were targeted as recipients for long line blue mussel culture (UNH <http://ooa.unh.edu>). Moreover, regulation of this new and unprecedented activity in both Hawaii and New England was of critical importance in defining its development. In Hawaii, collaboration between entrepreneurs, research institutions and supportive state agencies was essential to securing a legislative change that allowed the critical element of ocean leasing to move forward. A successful demonstration project operating at the time proved influential in gaining support for the legislative change. In New England, the permitting process was proactively assessed early on by researchers through a series of public and professional agency meetings. At the same time, an extremely large number of agencies and governmental bodies hold overlapping jurisdictions that complicated to a very great degree the process of obtaining permission to begin operations.

In Hawaii, federal funding from the Department of Commerce was found to have been of critical importance in supporting preliminary research over a range of related areas, including hatchery production, oceanography, legislative change and water quality monitoring (Personal Comm. Informants 3 and 5). Without these funds it would have been almost impossible for the nascent industry to advance to commercial status. The existence of academic institutions able to carry out such research and form partnerships with entrepreneurs was also of key importance. Interviews revealed a very modest economic impact and level of job creation arising from such operations, with up to perhaps a third of all directly and indirectly created employment categorized as skilled labor. In New England, the University of New Hampshire maintains a well funded NOAA funded research and demonstration project that has led to a proactive approach involving not only production research, but also outreach measures to incorporate commercial fishers, the public and local coastal residents. This led to a series of steps that resulted in commercial application of commercial blue mussel culture at exposed ocean sites, however falling under the aegis of the state of New Hampshire jurisdiction.

Some degree of social conflict has arisen, or looks set to arise as a result of these activities. In Hawaii, one prospective tuna ranching operation was stalled as a result of public resistance. Opposition came from fishermen, Native Hawaiians and homeowner's associations in whose view plane the project was to occur. In Hawaii, as well as in the Pacific Northwest opposition from fishermen, First Nations and environmental groups is vocal and widespread. In New England, little evidence of public opposition has formed to date although an earlier project to farm Atlantic salmon 37 miles off the coast was successfully challenged by the Conservation Law Foundation (Hoagland et al., 2003). Overall we found that because of the level of financial risk involved, those entering into the business deemed production of high value species essential. Proximity to existing academic and research capacity were extremely important. Given the unproven nature of such development, capital from private financial institutions was not available, meaning that public risk capital was crucial in facilitating preliminary research and development. Partnerships between entrepreneurs and academic institutions were frequently the conduit for this funding. The support of local bureaucratic and regulatory agencies was also of key importance, particularly during the process of securing leases for offshore sites, or in revising legislation to allow this to occur.

Economic impacts appeared likely to be very modest, although perhaps significant at a local level. Conflicts seemed most likely to occur over very large operations to be developed by outside investors, and with local resource users who felt their interests to be threatened by such development. Full disclosure of intended activities and extensive consultation with such groups appeared to be the most effective way to mitigate such conflicts. In this sense, the New England case warrants careful examination because UNH researchers targeted commercial near shore fishermen as likely operators of small blue mussel farms. As such, offshore mussel culture is cast as a supplemental activity for near shore commercial fishermen.

4. CANDIDATE SPECIES

4.1 Overview

For the remainder of this study, we will focus largely on those low trophic level candidate species suited to production in developing countries. There is currently very limited offshore production of these species, and a consequent dearth of literature that specifically addresses their production and social and economic outcomes. As a result we will draw on existing literature relating to culture of these species in near shore environments, and on interviews with experts to identify those organisms that may display some potential offshore. A brief summary of the characteristics relating to each organism and its culture offshore are included in Table 3.

As table 3 shows, there are few low trophic candidates for that offshore culture offers significant advantages or promise. Our focus on developing countries means, to a large degree, a focus on tropical and subtropical regions. Tropical marine environments are very largely oligotrophic. In general, a lack of available nutrients will place major environmental constraints on rearing filter-feeding organisms. The current high level of risk associated with farming *any* organism offshore also appears to make the choice of species that attract a high market value imperative. These two factors combined, severely limit the number of low trophic level species displaying signs of economic viability in the tropical offshore environment.

A number of our informants emphasized that any offshore aquaculture operation will require substantially greater levels of capital, operating costs and technical skills than it's near shore or capture fishery equivalent, thereby bypassing small-scale development scenarios. Perhaps cooperatives could surmount these barriers. In general however, we note that small-scale fishers and other coastal residents will be constrained in terms of ownership by the economies of scale necessary in the long run for offshore aquaculture operations to secure and maintain a competitive advantage.

Nevertheless, opinions on the feasibility of raising low trophic level species in the tropics varied among some of our informants. Informant 5, for instance, expressed the opinion that they could not envisage "a single [low trophic] species that would work". Informant 16, however, stressed that possible offshore sites, with nutrient enriched zones, have yet to be adequately studied and that some areas offshore display nutrient and temperature stratification, making shellfish culture potentially viable. Evidence from New England's commercial blue mussel effort requires close monitoring. In general, more systematic oceanographic research is required in order to determine viable biological characteristics at specific locations. Informant 2 emphasized that thorough investigation of sites on an individual basis was essential. This information could then be used to generate appropriate matches with the biological requirements of species to be cultured. In sum, much more primary oceanographic research needs to be conducted.

Sections 4.2 to 4.10 summarize the offshore culture potential of the species listed in table 3. Wherever possible our analysis takes into account a variety of factors for each candidate species. These include: the state of existing production technologies and expertise, market status and economic value, biological requirements, technologies necessary for production offshore, scale and cost of operations, social aspects, and economic feasibility.

4.2 Pearl Oysters

Marine pearl farming occurs in numerous locations across the Pacific Ocean. Fassler (1998) identifies Indonesia, the Philippines, Thailand, Malaysia, Vietnam, Myanmar, Papua New Guinea, India, the Seychelles, Mexico, Venezuela, Ecuador, Micronesia and Hawaii, in diminishing order, as those locations displaying the best potential for pearl industry development.

Table 3. Overview of Candidate Species' Potential

POTENTIAL SPECIES	COMMENTS
Shellfish	
Abalone	High value, high demand. Biology and culture well understood. Little culture of tropical species at present. No obvious economic benefits to offshore culture.
Giant Clams	Biology and culture well understood. Fairly limited markets. No obvious economic benefits to offshore culture.
Mussels & other Bivalves	Offer bioremediation possibilities. Successful offshore culture techniques in use and poised for commercial application in developed countries (e.g. New England, USA). Limited demand for product in developing countries. Major issues relating to contamination need to be addressed in post-harvest phases.
Pearl Oysters	A possibility given adequate nutrient levels, offshore environment <i>may</i> produce better quality and higher value pearls. Economies of scale would be necessary.
Trochus Sp.	Biology and culture well understood. No obvious economic benefits to offshore culture.
Seaweeds	
Milkfish, Mulletts, Rabbitfish	Biology and culture well understood. Limited export market. Extreme difficulty competing with pond reared and/or wild caught product.
Other	
Sea cucumbers	No obvious advantage to offshore culture.
Sea urchins	Possible application as part of an integrated system.
Sponges	Cheap and simple culture techniques. Market demand exists. Rarely cultured at present. Potential of production for biomedical uses may be considerable.

Pearl cultivation (family Pinctada) involves growout on lines suspended from rafts, and on floating lines moored to the bottom. Nuclei are implanted in the oysters and become coated with the substance that makes up the animal's shell, to form pearls. With the exception of implanting nuclei, which requires a professional technician, the skills required are simple, and the level of technology non-sophisticated.

Pearls are lightweight, non-perishable and simple to process, and the skills needed are those possessed by people who already work on the water because of the boating, diving and fishing aspects involved. Their culture is ideally suited to isolated island areas. Spat may be collected from the wild providing favorable environmental conditions and a sufficient wild pearl oyster population is present. Hatchery technology for pearl oysters is well developed, but the cost of obtaining seed oysters from a hatchery can be high.

Developments in Chinese freshwater pearl culture mean that small pearls no longer attract high prices. However, the market for large, high quality marine pearls is still buoyant and all indications suggest it will remain so. In 1996 the pearl retail market was valued at \$1.5 billion. The various species of oyster most frequently employed, (*P. maxima*, *P. margaritifera*, and *P. fucata*) yield pearls of differing appearance, making it possible for producing countries to differentiate their product for niche marketing (Fassler, 1998).

3000 pearl oysters are considered the minimum need to run a profitable near shore farm. Total farm size needed to maintain 3000 oysters in suitable condition to graft would be 12,000-15,000 oysters. Startup costs for such a farm would be in the region of \$17,000. After 4.5 years the farmer could expect to have recovered all costs and begun to make a profit. The farmer would need to work half time, with 1 or 2 part time assistants. Such small to medium scale pearl farming can yield modest profits and would be an excellent source of additional income for fishermen and coastal residents, as the work does not have to be carried out full time. By-products such as shells can also be used for handicrafts. The relatively modest startup costs make it a suitable family or community enterprise with associated benefits, although profits may also be modest (Haws, 2002). It should be noted however a farm further offshore would require greater expenditure on materials, time and travel, and would need to be considerably larger in order to offset these costs.

Tisdell (2000, pp35-36) estimates that at least 4000 people in French Polynesia derived their living from pearl farming or spat collection, and notes that, "pearls are the second foreign exchange earner, after tourism, and compose more than 95% of French Polynesia's exports". One important social consequence of this activity has been a marked reversal of rural to urban migration from the outer lying islands to Tahiti, and census figures indicate that standards of living have improved. This benefit has been somewhat tempered by the "many small family operations [that] went into debt to invest in pearl farming" and were unable to pay back their loans (Tisdell, 2000, pp35-36).

As with tuna ranching in Hawaii, attempts by "outsiders" to establish pearl farms in public waters have led to conflict, and in some instances, "newly arrived outsiders were met by violent demonstrations from the locals who believe that the riches of the lagoons are theirs by right and that no maritime licenses should be issued to aliens." The author also notes that there is, "an anarchic occupation of the public maritime domain, without any real control and an obsolete regulation of maritime concessions whereby oyster density within the lagoon is not considered." This has led to the over exploitation and degradation of some lagoons (Tisdell, 2000, pp35-37).

Pearl oysters require clean, clear, uncontaminated water. As filter feeders, they also require sufficient availability of food particles. Informant 5 felt that, given the oligotrophic nature of most tropical offshore environments, pearl oysters would not be a suitable candidate. Informant 2 was more optimistic, suggesting that lower water temperatures (such as are found offshore) foster pearls with better luster, and hence higher value. It was noted that spat fall has been found on Cates International Inc's moi cages in Hawaii, 2 miles offshore. Site selection was emphasized as critical, as was the need to test water parameters before going ahead with an operation, but the informant felt that certain offshore areas would supply conditions appropriate to growth and showed a great deal of potential.

A strong current can be beneficial as it provides constant oxygen and nutrients, and remove waste products from beneath the farm. However, fast currents and rough water can be difficult to work in and may also damage oysters (Haws, 2002). Haws also notes that theft of oysters is common, suggesting that location within view of the farmer's house is desirable. However, Fassler (1998) suggests, that a remote location may act as a better solution to these security considerations.

In summary, pearls can command a high value, and are an in demand product that is relatively easy to culture on a small scale at low cost. In many instances wild stocks have been over fished, and their culture can simultaneously act to enhance these stocks by acting as a "reproductive nodule" (Personal Comm. Informant 5). Their biology is well understood and adequate hatchery

infrastructure exists in many areas. Existing raft and line culture methods could be upgraded for the offshore environment, but would probably incur some additional initial costs in terms of extra materials.

Placement of farms offshore may help to avert the over-exploitation of lagoons, which has been known to occur, and might also mitigate user conflicts in these areas. There is some question as to whether offshore locations in tropical seas provide adequate nutrient levels, but it seems likely that with research, suitable areas might be located. One potentially beneficial application might be with finfish in an integrated aquaculture scheme (Personal Comm. Informant 17). Overall, cultivation of the various species of pearl oyster offshore appears to offer some prospects, contingent upon further applied research, although economies of scale would need to be attained to offset higher costs associated with travel and perhaps materials.

4.3 Sponges

Culture of sponges (Porifera) is an inexpensive, low technology activity and requires little specialized knowledge. Sponges are in demand worldwide for numerous medical, industrial, pharmaceutical, ornamental and household uses, and are also marketed to tourists in some areas (UHSGP, 1996). As Corriero et al., (2004:196) summarizes,

“The current world market for sponges is dominated by the artificial products, although the value and advantages of natural sponges are widely recognized. The present supply of natural sponges is outstripped by demand and is sustained worldwide by the wild Caribbean product... The availability of bath sponges has been recently reduced due to the depletion of natural banks due to the high fishing pressure... Moreover, at present, the need for good quality bath sponges is accompanied worldwide by a high demand for other sponge species which produce bio-active compounds useful for medical purposes.”

Of the entire marine fauna, sponges provide the best source of biologically active metabolites with biomedical potential (Duckworth and Battershill, 2002).

Sponge growing is a relatively new activity and is highly underutilized, given potential demand for products and ease of culture. In addition to reducing pressure on wild stocks, the activity can contribute to conservation and restocking, “as larvae produced by reared specimens can act as new recruits able to re-colonize adjacent coastal areas” (Corriero et al, 2004, p196). Of particular interest is the potential for producing chemicals for the pharmaceutical industry. “The market value of marine bio-metabolite is potentially huge if it is successful in all trials and approved as a drug. For example, the anti-cancer metabolite bryostatin-1 from the bryozoan *Bugula neritina* is estimated to be worth US\$1billion per year.” Up to one kilogram of bioactive metabolite is required for drug development alone. Unfortunately, many sponges contain only trace amounts of bioactive metabolites and the need for large quantities for trials has at times resulted in the near extinction of a population or species.” As a result, farming sponges “is considered to be the most cost effective or perhaps only method to guarantee sufficient supplies of some sponge metabolites” (Duckworth, 2001, p13).

Growing sponges on horizontal lines, anchored to the bottom and suspended by floats is the cheapest, easiest, most versatile method of culture. Sponge lines are normally suspended at a depth of 20-30ft but the depth of water underneath the hanging ropes makes no difference to growth. Strong currents will not damage sponges, but will make it difficult to work a site. Initially, sponges are harvested from the wild, cut into small sections and threaded on to nylon rope or a similar substrate. It is not unusual for up to 95% of cuttings to survive to commercial size if handled well. These explants continue to grow, reaching commercial size (for household and industrial use) in 2-3 years, and can be re-divided to produce additional explants (UHSGP, 1996).

In farming sponges for pharmaceutical products, ultimate shape and size do not determine market value, allowing for greater flexibility in developing new culture methods. Compared to wild (uncut) sponges, farmed explants appear to display higher levels of bioactivity in synthesizing greater quantities of bioactive metabolites, possibly in response to initial tissue damage. "Elevated levels of bioactive metabolites in farmed explants are a very promising result for the development and future success of commercial sponge aquaculture" (Duckworth, 2001, p17).

The materials to set up a small near shore sponge operation can be obtained for less than \$1,000, and processing the sponges to make them ready for the household and medical market is simple. Family members can participate in planting, maintenance and harvesting the crop, increasing a family's potential income, and the activity can provide year round income. A sponge farmer and assistant working 3 days a week can expect to plant 30,000 cuttings a year, earning \$10-12,000 (UHS GP, 1996). Informant 2 saw a great deal of potential in sponge farming, but felt that for producers in isolated areas marketing could be difficult and that linking buyers with growers could be problematic. However, UHS GP (1996) note that developing cooperative marketing arrangements between sponge farmers could avoid this difficulty and prove beneficial to new farmers.

Clearly sponge culture holds some considerable potential and warrants further developmental attention, providing an easily farmed product with a variety of uses that may attract high prices. The literature indicates that the high-energy environments found offshore are unlikely to affect growout. Corriero et al (2004, p204) state that, "vertical and horizontal systems proved resistant to deterioration due to water movement as well as to other ecological factors. Indeed, the wave dynamics do not represent a limitation if the rearing structures are placed under the wave breakdown zone (up to 10m depth from the surface)."

Two questions need to be answered more fully however, in order to determine whether sponges make suitable candidate species for offshore production: the first is whether sufficient nutrients and suspended matter exist in this environment to nourish sponges to a degree comparable to near shore waters. One potentially beneficial application might be with finfish in an integrated aquaculture scheme (Personal Comm. Informant 17). A related question in this regard involves overall water quality, especially if products will be used for medical purposes. The second (especially for small or part-time family based operations) question is whether there is any significant advantage to operating further from shore, in an area that experiences more difficult working conditions and a greater outlay of time and expense in terms of distance traveled to the site.

4.4 Giant clams

Giant clams belong to the family Tridacnidae. Nine species, occurring in 2 genera, exist and are distributed across the tropical Pacific. Traditionally their meat is used as a subsistence food source, and their shells have been used for tools, jewelry and ornaments. More recently the meat has become a delicacy, and the adductor portion is considered an aphrodisiac and can command high prices. The smaller species are also used in the aquarium trade (Ellis, 1999). The value of the giant clam for nourishment as well as profit has led to dramatic over fishing in the Pacific islands, as a result of which, all 9 species are listed as threatened under the Convention on International Trade in Endangered Species (CITES). Farming initially arose from stock enhancement efforts (Lee et al. 2001). Giant clam farming occurs in some form across the species' entire range. Countries involved include Australia, Papua New Guinea, Fiji, and numerous Pacific Island States.

Tridacnids feed by filtration, but have a symbiotic relationship with a photosynthetic algae zooxanthelle, which allow them to grow throughout their entire lifecycle with clean seawater and sunlight as the only sources of input. Light is important to clam growth and only mild water cloudiness can be tolerated.

Giant clams are raised in hatcheries, and then grown out in the marine environment (for as long as 6-10 years with the larger species). Initial growout takes place in sheltered coastal lagoons in wire cages, either on or just above the seabed, or in floating cages. Raising cages off the seabed helps to prevent problems caused by predatory snails, and protects clams from fouling by sand and silt (Ellis, 1999). Clams reared in floating cages suffer less predation by snails and tend to grow faster than those reared on the seabed because of greater light availability. However, mortality rates in surface cages can be negatively affected by the stronger wave action, and cages require a larger capital investment than the benthic method and are more visible to poachers (Lee et al. 2001).

Good water exchange rates are required, but must be balanced with providing adequate shelter for the clams during storms. Shallow sites are easier to work but may sustain more damage during bad weather. Regular maintenance of clams is necessary, but requires very little time; 3,000 clams for sale in the aquarium trade can be maintained in just 4-6 hours per week, and a farm of this size can be expected to yield modest financial returns (Ellis, 1999).

Export markets for giant clams as food do exist, but are currently limited to South East Asia and the Pacific Islands, although within these markets there is some room for supply to expand. A major drawback is the need for rapid live shipment in order to attract premium prices, which is both costly and difficult in remote areas (Lee et al. 2001). There is also a modest market for giant clamshells in Australia, estimated at 100,000 units per year (Crawford, 1990).

The basic technology required to farm tridacnids, along with the low production costs, the species' prevalence in developing countries and the widespread existence of hatcheries, makes them worthy of consideration for offshore development. There may also be some advantages to rearing the organisms close to the surface in floating cages, and availability of nutrients is not of paramount importance, though they will undoubtedly enhance growth rates. However, given the somewhat limited market for giant clam products, and the additional time and expense associated with raising them away from the shore, they should be more carefully considered as a potential candidate species. .

4.5 Trochus (Topshells)

Trochus are gastropods, harvested for their pearlescent shells, and to a lesser degree, meat. Small trochus are also sold in the aquarium trade as cleaners for marine tanks. The most widely cultured species *Trochus niloticus*, is the largest of the topshells and is distributed throughout reefs in the Indo-Pacific oceans. It has been widely over fished across its range. This problem has generated interest in restocking programs using hatchery-reared juveniles, and attempts have been made at enhancing trochus fisheries in this manner in a number of different locations (Amos and Purcell, 2003).

Hatchery technology for mass production of trochus is easy, standardized and cost effective and the larval cycle is simple. Larvae do not require feeding during the planktonic phase, and juveniles are easily transported for stocking. Seeding for stock enhancement is a low cost, low technology operation than can be conducted on a small scale or commercial basis and suits itself well to adoption by artisanal fishers. Restocking efforts using juvenile trochus tend to be more successful when they are released at larger sizes. Production of large juveniles (10-40mm) is not economical in a hatchery, but may be achieved by growout in cages, either fixed to reefs or floating (SPC, 2003).

Amos and Purcell, (2003) finds that intermediate cage culture in reef-based cages may be an effective approach for providing sub-adults for restocking. This intermediate culture allows the growout of hatchery-produced juveniles to a large size while offering protection from predators, and may be more cost effective than the free release of smaller juveniles. Trochus feed on algae and detritus, and can be reared in cages without feed supplements if algae cultures are established in

them. This is achieved by placing pieces of dead coral rock with established epilithic algae inside the cages.

Floating cages have proven less problematic than benthic cages, although in one experiment they yielded lower rates of shell growth than benthic cages. This was felt to be an effect of stocking density, with 95% of trochus in the benthic cages escaping or dying compared to 48% in floating cages. The effect of stocking density on growth is considered to be mainly an effect of competition, and it is suggested that additional feed in the form of macro algae could circumvent this problem. Fouling of the cages was found to impede water flow, and it was suggested that placing cages in areas of higher water flow could limit fouling and yield better results (Amos and Purcell, 2003).

Clearly then, cage culture of trochus is possible, and might be feasible offshore. Although current efforts focus on enhancing fisheries through restocking, it seems that there is potential to grow the organisms out to maturity. Such an effort would probably require the regular addition of algal feeds in order to achieve maximum growth rates, and location of cages a significant distance from shore might make this impractical.

It remains to be seen whether such an activity would make economic sense, but it could conceivably do so given the well established market for trochus shells, and reportedly high prices on the Japanese market for trochus meat. A system of processing trochus meat for export has yet to be developed, although it is believed that the methodology would be relatively simple (SPC, 2003).

4.6 Abalone

23 species of the large gastropod abalone make up the family Haliotis. Of these, 3: *H. diversicolor diversicolor*, *H. diversicolor supertexta*, and *H. asinina*, are found in Southeast Asian waters between Southern Japan and Thailand. Three other species occur in the waters off Mexico, 2 of which: *H. rufescens* and *H. fulgens*, are farmed. None of the 3 tropically occurring abalone species is farmed to any significant extent, but Haliotis culture is well established, and their biology and hatchery production techniques are well understood (Spencer, 2002).

Abalone can command extraordinarily high prices, and China and Japan, together with Southeast Asia consume more than 80% of the world total. Annual aquaculture production of abalone is 8,000 tons. Many abalone fisheries are severely threatened by over exploitation, and this relative scarcity and attendant high prices have generated a great deal of interest in their production, with industries established in numerous countries as diverse as, China, Taiwan, Chile, Mexico, Ireland, South Africa, the US, New Zealand and Indonesia. This activity means that hatchery, nursery and growout technologies are readily available (Spencer, 2002).

Growout occurs either in land-based ponds, or in marine systems generally composed of barrels hung from anchored ropes. Some operations have also experimented with sea cages. Marine systems are generally considerably cheaper to operate than land based ones, but suffer from a more limited control of environmental parameters. At sea, abalone is generally fed macro algae rather than formulated feeds as the breakdown of these unstable artificial feeds creates pollution that cannot be adequately managed. As a result, marine grown abalone show a poorer dietary response than those in land based systems and require frequent feeding and cleaning, making the activity somewhat labor intensive (Viana, 2002).

Tropical abalone, such as *H. asinine*, command lower prices than their northern counter-parts based on distinctions of size, texture and taste (SPC, 2003). However, they display considerably greater growth rates, growing up to 4.5cm per year, as compared to temperate species, which only grow around 2.5cm per year. As a result, growout cycles are short for tropical species, ranging from 10-18 months (Viana, 2002). Abalone make ideal candidates for polyculture in seaweed farms because of their dietary requirements. Most tropical abalone is sold live, meaning that airfreight must be available. However, the product may be canned, frozen, dried or sold in value

added forms such as soup, making it a good option where canneries or seafood processing facilities are already in existence (SPC, 2003).

Overall, abalone production may show some potential in tropical countries given the fast growth rates and under-utilization of tropical species, simple culture methods, and established hatchery expertise. It remains to be seen, however, if production in a more hostile and exposed environment offers any significant advantages over culture located closer to shore.

4.7 Seaweeds

“The intensive culture of aquatic plants represents a major proportion of global aquacultured production, value and trade” (McLean et al. 2001, p1). In 1994, between 5 and 7million mt were cultured annually. Over 50% of seaweed production is used for human consumption and the value of food macrophytes is six times greater, on a raw materials used basis, than that employed by industrial concerns. However, wild harvests of seaweed far outweigh aquaculture production, and approach 320,000,000mt/year. China is by far the greatest producer, followed by Taiwan and Japan (McLean et al. 2001).

Seaweeds can be classified into 3 broad generic groups based on pigmentation: brown, red and green. Botanists refer to these groups as Phaeophyceae, Rhodophyceae and Chlorophyceae respectively. Brown seaweeds are often large, while red and green seaweeds are usually smaller (McHugh, 2002). Besides consumption for food in Asia, seaweeds are utilized industrially for extraction of alginate, agar and carrageenan. These thickening agents are used in the food industry, in a range of products such as shoe polish, oil drilling mud and toothpaste, and in the microbiology and pharmaceutical industries (McLean et al. 2001).

Alginate (worth \$213million/ annum) is extracted from brown seaweeds, all of which are harvested in the wild. Agar production (worth \$132million annum) is from 2 forms of red seaweed: *Gracilaria* and *Gelidium*, some of which comes from cultivated sources. Carrageenan production is derived largely from 2 sources of red seaweed: *cottonii* and *spinosum*, both of which are cultured, particularly in the Philippines, Indonesia and Tanzania. Green seaweeds, such as nori, are those usually utilized directly as a food source (McHugh, 2002).

Because of the low prices paid for industrially utilized seaweeds (e.g. \$200/ mt dry weight for seaweed destined for carrageenan extraction), and the high level of labor required, production of brown seaweeds for alginate extraction is economically unviable in any form. Carrageenan extraction from red seaweeds requires minimum production volumes of at least 1,000mt dry weight annually to make it viable, and even then, is only possible in locations such as the Philippines where labor is sufficiently cheap (McHugh, 2002).

The market for seaweeds is buoyant and ever expanding, and production may be economically viable on a large scale in countries with low labor costs. However, it is hard to envision, given these limitations, a scenario under which exposed culture would represent an economic advantage over near shore culture. Additionally, marine algae must be grown close to the surface where photosynthesis can take place. This represents a major limiting factor to production offshore as they are susceptible to damage by the severe wave action that can occur at these exposed surface sites.

4.8 Bivalves

Bivalves, in particular mussels (Mytilidae), are the only low trophic level organisms presently cultured to any tangible degree in exposed environments. As such, they offer the best immediate prospects for offshore development.

China is known to employ shellfish in large quantities as biofilters in the waters off Shanghai and Hong Kong to denitrify plumes of eutrophic surface runoff that extend far out to sea. Taiwan may be engaged in similar efforts. Information on these bioremediation activities is scarce. It is unclear whether the resultant product is eaten, but issues of bioaccumulation of heavy metals and

other toxins, and possible contamination by fecal coliforms make this unlikely (Personal Comm. Informant 14).

In the US, both Massachusetts Institute for Technology (MIT) and University of New Hampshire (UNH) have undertaken extensive studies to determine the feasibility of raising mussels on suspended long lines in exposed areas. Informants 15, 16 and 18 have mentioned that this form of offshore aquaculture is currently applied on a commercial scale involving near shore fishers working under the organizational structure of a local fishermen's cooperative.

In 1998, MIT began experimental blue mussel (*Mytilus edulis*) growout on submerged longlines 9.5 miles southwest of Martha's Vineyard. This resulted in the harvest of over 3000lb of mussels of "exceptional taste and meat quality" in the spring of 2000 (Paul, 2000, p1). The project achieved all of its engineering, design and feasibility objectives. Spat recruited naturally on the longlines, and the mussels generated a monoculture as they grew. A 100ft fishing trawler with powerful winches was used for harvesting and found to be well suited to the job, and the system sustained no damage from hurricane Floyd. It was concluded that; "the mussel growout experiment has proven that a significant new source of protein can be accessed in the coastal offshore waters south of Cape Cod by deploying submerged mussel growout harnesses. The natural growout time seems to be in the 9 to 12 month range for smaller cocktail sized mussels. 12 to 18 months seem to be required to grow larger size mussels" (Paul, 2000, p5).

A similar project organized by the University of New Hampshire "demonstrated the biological and engineering feasibilities of this new kind of technology. It has always been assumed that estuarine environments are optimal with respect to the important temperature and food availability (phytoplankton concentration) parameters. These projects have revealed that this assumption holds in the coastal ocean as well" (Hoagland et al., 2003, p8).

New Zealand, which has widespread culture of green-lipped mussels (*Perna canaliculus*) is planning to expand offshore, with proposals for farms of up to 4,000ha each up to 7km offshore in the exposed waters of Pegasus Bay, Clifford Bay, Cloudy Bay, Hawke Bay and the Bay of Plenty (Lloyd 2003). Some initial offshore mussel farm development has also occurred in Japan (Jeffs, 2003).

Growing mussels offshore appears to offer some significant biological advantages over near shore waters. Pea crabs live inside mussels, pirating food and reducing market value. It appears that growing suspended mussels off the bottom can reduce invasion by these and other parasites. The lower nutrient loading of offshore waters also reduces fouling by epiphytes, which occurs inshore and necessitates cleaning the product prior to going to market. Mussel pearls, which originate from grains of sand, are also undesirable and are also likely to be avoided by keeping the mussels clear of the ocean floor (Hoagland et al, 2003).

Informant 16 noted that increasingly sophisticated ocean observing systems are showing stratified nutrient layers within ocean waters. By building real-time monitoring of water parameters may make widespread mussel culture appropriate. These layers will cause differing growth rates depending on where operations are sited, and a situation was envisioned where (a long time in the future) bivalve aquaculture would take on a horizontal, rather than vertical form in order to more fully integrate with these oceanographic characteristics. The informant also stated that deepwater (offshore) mussel culture has reached a stage of development where it will happen all over the world.

This, or any other offshore development, would have to be on an industrial scale in order to make it economically feasible, with perhaps 120 mussel lines having to be deployed on an offshore farm to make it viable, compared to perhaps just 10 to 15 for an inshore farm. In the informant's opinion, moving even a few 100 meters offshore will require higher organism densities and product flow, major capital, and the surmounting of logistical issues, meaning that "there will be

no mom and pop open ocean aquaculture” (Personal Comm. Informant 16). For the United States, Hoagland et al (2003), project a \$1.2 million up-front investment to start up a 125 long line offshore blue mussel farm producing 1,000tons/year after 5 years, at a farm gate price of \$0.60/lb. The crucial component needed to achieve economies of scale depends on a customized mussel vessel devoted to this activity only (Personal Comm. Informant 18).

A major issue for shellfish producers is contamination. Importing countries and regions, in particular the EU, impose extremely stringent criteria. Standards such as ISO 65 and country of origin labeling will play an increasingly important role. These requirements will drive standards and production practices for producers, particularly in the developing world. Even the MIT and UNH offshore mussel programs reportedly experienced some concerns about bringing the product ashore for sale where statutory monitoring by the state agencies does not take place, meaning that the product cannot be certified as safe for human consumption (Personal Comm. Informant 14).

Informant 14 identified the estuaries of the world’s great rivers (e.g. the Amazon, Congo, Nile, etc) as prime sites for shellfish culture. These areas harbor large, food-impooverished human populations, and the vast estuaries distribute high nutrient loads and food concentrations all the way to the continental shelf and offer high levels of mixing and flushing. However, the concentration of heavy metals and other pollutants in the flesh of these creatures, as well as the presence of sewage and toxic algal blooms, may well make shellfish grown there unfit for human consumption or impossible to export without further depuration and testing of the meat.

It is possible to process contaminated shellfish in order to make them edible, but this process is somewhat problematic. For instance, “in 1981, a trading company began an operation of depuration or controlled purification of oysters from the estuary [in the Philippines], blast freezing them, and exporting the product to Singapore. However, this effort was short lived because the gross sewage contamination in the estuary did not allow for an adequately safe product to meet international public health standards” (Rice and de Vera, 1998, p21). Such depuration operations are expensive to run and, even if processing is fully effective, it is hard to envisage a situation where it would be cost effective, unless perhaps on a large industrial scale.

Mussels are grown on a commercial scale in the Philippines, Thailand, Chile, Malaysia, Singapore and South Africa. However, mussel production in tropical countries does not contribute significantly to total world production because of a lack of local demand and consequently low market prices. This is in marked contrast to the situation in the developed world, and although “huge potential exists for farming mussels in the entire belt of maritime tropical countries,” except in places where tourism related demand for exotic seafood is high, mussels are “eaten by only a small proportion of the population who live near the coastal regions.” This situation is promoted by the “serious gaps” that “exist in handling, packing, preservation, processing and by-product development.” For example, the “short self-life associated with traditional methods of processing and under-developed transportation prevented domestic market expansion in Thailand.” And “in India, marketing has been identified as a major constraint for mussel development.” The culture of oysters also follows a similar pattern and set of limitations across the tropics (Joseph, 1998, pp323-327).

This overview has dealt very largely with the culture of mussels. Mussels offer some offshore production advantages over other bivalves. Spat recruits very readily to manmade substrates such as longlines, thereby negating the need for hatchery production of larvae. The resultant mussels are hardy and aggregate at very high densities, forming monocultures that require little daily husbandry. This makes them the best candidates for offshore culture, where the minimization of travel times and costs is at a premium. In New England, the activity is viewed as an interim measure to allow displaced commercial fishers to remain, in some capacity “on the water” (Personal Comm. Informant 15).

Culture of other families of bivalve, in particular oysters (*Ostreidae*) and scallops (*Pectinidae*), is well understood and these organisms can command significantly higher prices than mussels. UNH has experimented with some offshore culture of sea scallops (*Placopecten magellanicus*) (Howell et al, 2003). However, they do not lend themselves so readily to simple longline production as they will not naturally aggregate on manmade structures to the extent that mussels do. Harvest of scallop and oyster spat in the wild is possible, but the process is somewhat more difficult than for mussels, meaning that the hatchery culture of larvae may be necessary. Their culture is generally more complicated, time consuming and expensive, and the harvest process more difficult. Despite these limitations, such activity is technically feasible, and as the deep water production of mussels becomes more fully established and better refined it may bring with it technical advances that make culture of other bivalves in a similar manner a viable option.

Offshore longline production of shellfish also lends itself well to integration with, and adoption by, longline fishermen (Tango-Lowy and Robertson 2002). Increasingly tighter regulations are curtailing longline fisheries for species such as billfish and tuna, and the heavy lifting and winching gear that long lining boats possess are ideally suited for minor modifications in the deployment and harvesting of shellfish longlines (Personal Comm. Informant 14 & 15).

Despite huge untapped production potential, offshore mussel and other bivalve culture does not presently appear to hold great promise for tropical developing countries given their low domestic demand for shellfish, although this cultural limitation may change over time. Production for export to developed markets might be an option provided ways could be found to meet stringent import requirements, either through better post-harvest processing or improvements in water quality monitoring techniques that could satisfy the demands of importing countries, but neither scenario appears imminent. New Zealand's green-lip export mussel culture industry currently sets the world standard (Personal Comm. Informant 18). Informant 2 stated that a number of bivalve species with low nutrient requirements occur throughout the tropics. These could be well suited, from a biological perspective at least, to production in offshore oligotrophic environments. The informant also commented that in countries such as Mexico subsistence shellfish culture techniques could provide an alternative stable form of employment. For developed countries, however, longline mussel culture offers the most immediate and viable form of low trophic offshore aquaculture.

4.9 Low Trophic Level Fish Species

Because of similarities, the 3 main candidate groups of low tropic finfish will be considered together. They are: Mulletts (*Mugilidae*, in particular *Mugil Cephalus*, which is the most commonly cultured), Milkfish (*Chanos Chanos*) and Rabbitfish (*Ciganidae*). These fishes possess a trophic level of around or just over 2.0, with the exception of mullet, which have a level of around 3.0 in their larval stages (www.fishbase.org).

Mulletts live in both brackish and saline environments, as do milkfish, and are obtained both through capture fisheries and aquaculture across the tropical and subtropical zones of the Pacific and Atlantic oceans. The lifecycle for *Mugil Cephalus* has been closed.

Milkfish are widely cultured in ponds and, to an extent, in pens and floating cages throughout Southeast Asia and the Pacific islands, as both a food source and as bait for the tuna fishery. Hatchery seed production is well established. An earlier effort in the Philippines took place in the mid-90s and involved milkfish culture in an Ocean Spar Sea Station cage. Fish produced exhibited better flesh quality and color than that from pond culture. Reasons for discontinuing this project are unknown (Personal Comm. Informant 17).

Rabbitfish are distributed across the tropical and subtropical western Pacific, and are both cultured in cages and captured from the wild, although wild capture is more common.

All of these groups represent an important source of protein for populations in the developing countries where they are found. Export prospects are limited however, as they are not widely eaten in developed countries apart from niche ethnic markets. If market acceptance was to take hold elsewhere it would require significant time to establish shifts in consumer behavior where these fish are not well known (e.g., Tilapia market development). Informants 1, 3, 4, 5 and 16, when questioned about the potential of these species in offshore aquaculture, unanimously stated that they were not viable from an economic standpoint, given their low market value, low export potential, and the increased costs inherent in operating offshore. For example, informant 3 noted that in the US it would be impossible to compete with \$1.50/lb wild caught mullet from Florida, or pond-raised milkfish from the Philippines. At the same time, scant evidence indicates that a better quality product could be produced in offshore environments in terms of flesh, color and perhaps taste versus pond produced finfish. Because of these initial economic and market constraints it is unlikely that any commercial offshore aquaculture will proceed for the above finfish species in the foreseeable future.

4.10 Sea Cucumbers and Sea Urchins

Sea urchins belong to the class Echinoidea, and are omnivores, feeding largely on algae, although they consume other food sources where available. Sea cucumbers, class Holothuroidea, are soft bodied bottom dwelling animals belonging to the same phylum as urchins, and are largely unselective in what they eat, ingesting large quantities of sand or other bottom substrate in order to remove small organic particles.

Demand for beche-de-mer, a product made from the dried body wall of sea cucumbers, is high and sea cucumber products may fetch up to \$100/kg in some Asian markets. Natural stocks have become depleted or heavily regulated in some areas. Demand for sea urchin roe is large in many Asian markets, where it also commands high prices. Urchin stocks are depleted in many areas because of over harvesting (SPC, 2003).

Some experimental hatchery work for sea cucumbers has been undertaken in a number of locations, mainly for stock enhancement, but there is no known commercial hatchery production at present. Urchin production biology is more thoroughly understood, although hatchery work is largely for ranching or stock enhancement purposes. It is possible to produce large numbers of urchins in land-based facilities, but because the process is very space and labor intensive it is unlikely that such land-based grow out is feasible (Harris et al, 2003). The University of New Hampshire has conducted experiments growing sea urchins in suspended marine cages, which yielded promising results, particularly when placed adjacent to finfish cages. At time of writing the experiments are incomplete (Harris, 2003).

Sea cucumbers appear to be unsuitable candidates for offshore aquaculture given their feeding habits which require a granular substrate and their, as yet, limited hatchery production. Urchins appear slightly more attractive, given larger international markets, and established production techniques, but there is no compelling evidence to suggest that, produced offshore, they could compete economically with product from wild and stock enhanced fisheries. However, one potentially beneficial application might be in polyculture with finfish whereby grazing urchins could reduce fouling of offshore cages. This strategy has several drawbacks, however, in that sea urchins are likely to become a nuisance to fish farming operations (e.g., net changing), might cause damage to the netting material, and will have substantial off flavor issues if consuming excess fish feed (Personal Comm. Informant 17). A recent study has also found that placing urchins on pearl oyster lines was beneficial in reducing fouling of lines and shells, thereby increasing water flow and growth rates (Lodeiros & Garcia, 2004).

5. ANALYSIS

Among existing research, demonstration projects, ventures and nascent commercial operations we find an overwhelming preference for high-value finfish culture; high value product being deemed

necessary to offset the large costs and risks associated with farming in exposed ocean sites. This focus has tended to obscure attention on the utilization of low trophic species.

Offshore aquaculture exhibits fragmentary development at a number of locations occurring in at least 30 countries. In large measure, independent consultants, academics, and administrators are working closely with private growers to advance demonstration projects into commercial ventures. Overall, the activity as research, as demonstration projects and as joint public-private ventures is growing in significance. Our case studies, review of literature, and interviews indicate that the offshore farming of low trophic species may become viable in certain instances and under appropriate environmental and social conditions, yet due to variables relating to site selection, appropriate technology, capital risk and the organization of production, we find the range of candidate species and culture sites limited. In addition, the social and economic dimensions of such development are also poorly understood. *We suggest however, that in the immediate future, longline mussel and sponge culture appear to warrant further examination.*

Our analysis of low-trophic offshore aquaculture indicates that a number of development criteria will have to be met. Below we group some findings drawn from this report.

Site Selection

In making the decision to farm any offshore site there must be clearly demonstrable environmental, biological and economic advantages over other forms of production such as capture fisheries and coastal aquaculture in order to justify the limitations, risks, high start-up and operating costs imposed by the exposed ocean environment.

As a number of our interviews illustrate, a top priority is for further oceanographic work that can accurately identify appropriate sites and environments. Initiatives such as an ongoing University of Hawaii ocean mapping project using GIS systems to identify potential aquaculture sites will go some way toward providing this data. A clear micro understanding of the biological characteristics of individual sites is equally important, especially in the case of filter feeding organisms. For these animals, the question of whether sufficient nutrients, water column stratification and suspended matter exist offshore to nourish bivalves, sponges and even pearls to a degree comparable to near shore waters warrants considerable examination.

Thorough planning involving the mapping of ocean uses such as fishing, shipping, commerce, recreation, and habitat important to other marine organisms and users will help eliminate a great number of unsuitable sites early on and may serve to preempt conflicts and environmental degradation in the activity's later stages. Land based infrastructure and ancillary support facilities (e.g., hatcheries, processing facilities, transport hubs etc.) must also be taken into account. Pressure from offshore aquaculture on infrastructure with finite capacity (for instance small ports) can create potential flash points for conflict with existing users, as was evident in Kawaihae Harbor, Hawaii. In particular offshore produced products must also have rapid and reliable access to markets and critical infrastructure if operations are to succeed. A cautionary approach must be exercised by attempting to understand as fully as possible the numerous environmental, economic, social and regulatory variables that will determine an operations' success or failure. As of this writing, we have not come across any definitive assessment of these variables. The closest approximation however rests in New Brunswick where a major investment and move offshore pertains to salmon farming in the Bay of Fundy (Bridger and Neal 2004). The blue mussel component of the UNH offshore aquaculture project also somewhat demonstrates some of these more holistic approaches. The greater the quality and detail of information (e.g., oceanographic, social and economic) available for planning purposes, the better the chances become for low trophic aquaculture in exposed ocean conditions.

Technology

This report has identified a number of low trophic candidate species that may be suitable for exposed ocean rearing. However, the biological and technological factors that determine whether they may be successfully

cultured in the open ocean are poorly understood and require much further research, especially when developing countries are considered.

The effects of disease and predation are largely unknown for many low trophic species covered in this report. In this regard, Prince Edward Island's experience with a 1987 algal bloom, effectively shutting down the industry for one year, warrants full consideration (Hoagland et al., 2003). It is important to further note that the environmental and biological assessments of small demonstration projects do not equate with the same biological magnification scale of potential impacts that large industrial farms in the open ocean could potentially have. Determining the benefits or otherwise of hatchery production as well as sourcing seed from the wild will also require concerted attention. Important factors pertain to assessing population genetic impacts, as well as harvesting techniques, management, monitoring, and processing considerations. All of these factors must be considered prior to embarking on actual production projects.

Low market value, with few exceptions, is a trait common to low trophic species, which acquire any value added attributes further along the commodity chain. As a result, low trophic aquaculture systems must be of a relatively large scale, involving industrial processes for economically viable cultivation to take place. Achieving economies of scale may pose a barrier in many cases. However most, if not all, low trophic species and their culture systems offer a primary production advantage of being simpler and lower cost than high trophic finfish culture. The basic anchor, float and line arrangements used to rear many of the organisms identified in this report could be improved upon, enabling them to function offshore, and making them more appropriate to developing countries than the costly sea cages systems employed to rear high trophic finfish. This said, offshore low trophic technology would be significantly more expensive than equivalent near shore systems, at minimum in terms of fuel and time, and would have to display significant advantages and benefits to warrant deployment. Post harvest facilities must also exist to process raw materials.

Property and Regulation

Offshore aquaculture requires secure private property arrangements to 1) exclude outsiders and 2) attract and recoup investment. Early offshore adopters have found it necessary to work within or redefine complex and restrictive regulations.

The establishment of private property rights is the case for aquaculture in exposed ocean sites. Depending on the country, region and locale, these rights may fall beyond immediate state jurisdiction. This complicated and frequently controversial legal-political area is likely to display certain similarities everywhere, but the minutiae of details may vary down to a local level, making sweeping generalizations impossible. Thus, situations will have to be addressed on a case-by-case or country-by-country basis. These remarks also equally apply to traditional or aboriginal marine tenure systems. In Thailand for example, a Department of Fisheries proposal evoked almost immediate concerns over violation of the Thai Constitution due to the permitting and privatization of public property for aquaculture purposes (Ekachai 2004). In countries such as Taiwan, aquaculture operators work through local fishermen cooperatives thereby securing exclusionary rights to operate offshore farms. In the US, the ability to establish offshore farms varies from state to state, entrusted with upholding of National Security and Commerce, Public Trust, NEPA and other statute and legal measures. Major legislation will have to be in place or further needed to facilitate operations beyond state or provincially controlled waters. In all cases the complex array of property rights, traditional tenure, leases, permits and negotiation through many layers of multi-agency jurisdiction, statutes and laws present a challenge both for administrators, prospective operators and regulators.

Environmental and other regulations also act as an obstacle to the swift deployment of offshore farms. These limitations are generally felt to impinge most heavily upon the activities of producers in developed countries, offering a distinct advantage to producers in the developing world. This is not to suggest that environmental concerns are any less pertinent in these countries. Lower labor costs apparent in developing countries also offer an advantage in the global

marketplace. Given Asia's history and expertise in aquaculture, coupled with these factors it seems probable that the region will emerge as a leader in offshore finfish and, perhaps ultimately, low trophic production

Standards

Offshore aquaculture of finfish and possible low-trophic species will not be a small-scale form of aquatic husbandry. Achieving economies of scale will require large production volumes destined for export markets that meet internationally recognized standards.

Products for human consumption will have to meet a growing body of standards including those generated by the EU and International Standards Organization, and conform to food traceability measures such as country of origin labeling (COOL, in the U.S) that determine whether they can be sold abroad. These measures are particularly important where they concern the importation of shellfish, and will increasingly drive production practices. For products reared in an open environment, testing for coliform and other contaminants is essential and can add to overall operating costs. However, advances in real time in situ water quality measurement may help address some of these issues. *Voluntary standards as currently practiced will simply not be adequate to ensure environmentally sound, high quality and contaminant free products.* When products are destined for human consumption, reliable and rigorous requirements for monitoring, inspection and enforcement of standards will add significant costs, some of which may be borne by operators. These considerations may not be necessary for those organisms grown for pearls, ornamental, medicinal or chemical products.

Institutional Capacity

As our Hawaiian and New England case studies show, certain structural conditions are emerging for the establishment of offshore aquaculture.

Offshore aquaculture development is taking place on a local, state and regional basis. An extensive network has clearly formed involving all of the major actors. An effort is being made by the Irish Sea Board to create an international offshore aquaculture center focused on large-scale development in developed countries. While there is no centralized institution, the large risks associated with these novel and unproven production systems discourages investment from private financial institutions, meaning that risk capital must come either from private individuals or public funds (the latter being more common). Direct government investment in private companies is unlikely, so funding for research and development is generally delivered through research institutions, particularly universities. Universities (such as the U.S. Sea Grant College Program) provide the technical and academic expertise necessary to advance research and demonstration projects in new areas. These institutions find it easier to attract funding in partnership with industry or in developing projects with readily identifiable commercial applications. Partnerships with companies help spread risk and benefit participating parties, especially where successful demonstration projects are established, as these help to attract further interest and investment. Entrepreneurs ultimately shoulder the bulk of risk when entering into full commercial operations. With limited capital, small ventures can quickly fail due to insufficient funding or the encountering of technical and environmental obstacles. Entrepreneurs are the first to test legal and regulatory hurdles that may hinder the activity or encourage further interest, investment, research and collaboration if they prove successful. This scenario is likely to be aided by the presence of regulatory agencies or government that supports such activity. This is certainly not the only manner in which offshore aquaculture development can occur, but some sort of variation on the theme outlined above will make its adoption far more probable than if less of the elements identified exist concomitantly. Should low trophic offshore aquaculture take off in the developing world, it is more likely to result from centralized public support, investment and partnerships than from a local entrepreneurial base.

Organization of Production

In almost every case covered in this report, offshore aquaculture is conducted as a private business. In general, individual entrepreneurs and small aquaculture companies are actively rearing offshore-produced finfish for market. We are certain that large aquaculture corporations are investigating the feasibility of the activity. That said, alternative organizations could be considered involving:

1. Public bioremediation projects using shellfish, such as in the case of China
2. Fisher coops using low trophic species in areas that are socially and economically viable such as the case of Taiwan and New England.
3. Enhancement aquaculture involving rearing of low trophic species at artificial reef sites, platforms and integrated with finfish.

At present, the likelihood of the above organizational forms occurring faces significant obstacles due to the increased costs, scale and capacity required on the part of cooperative or public authorities responsible.

Conflict

Social conflict over the implementation of offshore aquaculture may occur for a variety of reasons and can originate from citizens, environmental, conservation, indigenous/aboriginal and fishing groups. *Where aquaculture threatens to privatize, threaten or limit access to water, or creates real or perceived competition in the marketplace, fishers are often the most vocal critics.* There is growing fishing industry-environmental group opposition to open ocean aquaculture in the United States with other groups in different countries monitoring the activity. At the same time, Greenpeace Israel has issued a statement endorsing open ocean aquaculture in the Mediterranean (Mizrachi 2004). In essence, conflict over offshore aquaculture occurs over direct competition for oceanic space and revenue. This is most evident in the case of fishermen who are traditional users of fish stocks (Roberson and Carlsen 2003). Alaskan fishing groups for example have long opposed finfish aquaculture in State waters, with offshore initiatives being greeted with stiff opposition. Conferring private property rights in commonly held areas has always been a contentious issue, but may not be insurmountable. Informant 5 gives an example from the Solomon Islands where, despite over exploitation of the wild pearl fishery, there was strong resistance to the establishment of pearl farming because of the privatization it demanded. A handful of farms did start however, and over the course of 20 years a successful industry has replaced the wild fishery and been accepted by the population. Such conflict is best avoided at a project's inception by full and transparent public disclosure of intentions and acting upon the input of members of the public and interest groups to avoid their disenfranchisement wherever possible. On the surface, the case of the New England mussel culture project illustrates what can be done to date through open and transparent public hearings and outreach efforts. In much of the United States however, the NOAA has been relatively secretive about this process and has subsequently provoked coastal fishing and environmental groups to demand more strictures, oversight and accountability over their plans.

6. CONCLUSION

Worldwide demand for finfish and shellfish products is expanding rapidly with aquaculture accounting for one third of world supply. It is a given that traditional capture fisheries will be unable to sustain growing demand and supply indefinitely. Production of aquacultured products will continue to expand accordingly. Developmental pressures are greatest in coastal regions and competition for resources such as land and water and, perhaps, dwindling access to water of a high enough quality to sustain aquaculture, may over time create more and more compelling reasons to locate production facilities further offshore. At the same time, there are currently few examples where this degree of competition provides sufficiently compelling reasons to make the high risk leap offshore to *sustainable* aquaculture development. Indeed, one correspondent went as far as to dub offshore finfish aquaculture as "technology in search of a problem."

Offshore aquaculture as a whole is in its infancy and has yet to prove itself technologically, economically, environmentally and socially feasible, yet the field is evolving rapidly, and will in all probability resolve at least the majority of technical issues in the coming years. Its economic performance, though somewhat buffered at present by public investment, may be eventually resolved in the marketplace. Environmental concerns still persist, especially in the case of very large or numerous facilities, but rigorous site selection and monitoring may contribute towards mitigating harmful impacts. Social effects remain largely unknown, although our work in the US suggests that in developed countries some modest local economic impacts and creation of skilled jobs will result from OOA. A fuller accounting of the potential impacts including negative ones must become a priority. It is difficult to speculate over what the benefits or otherwise may look like in developing countries.

Offshore aquaculture is most likely to succeed were it supplies a product that has cultural significance but is no longer available from traditional sources in sufficient quantities, or where it supplies a unique product that cannot be substituted. This scenario appears to be unfolding in areas where capture fisheries are depleted and show no signs of recovery in the long run. Hence conflicts with local populations are minimized and the activity is accepted. This scenario seems to be unfolding in New England and New Brunswick but more research is required to verify aquaculture's acceptance here. Offshore aquaculture is likely to offer advantages when not in direct competition with existing forms of capture fisheries, or where the biological requirements of a species can only be optimally met offshore. For the foreseeable future then, due to these factors and the inherently high risks and capital outlay involved, most products will be of high value and destined for niche luxury markets. Offshore aquaculture's main economic impact is likely to result from regional or international export revenue, with some localized benefits resulting from very modest job creation.

Initially governmental and agency support, both capital and institutional, will need to play an important role in facilitating research, development and demonstration projects where OOA is deemed a desirable undertaking. As technologies and production methodologies become established, private investment is more likely to occur and technology transfer will begin to diffuse to new locations. Ultimately it will be difficult for an offshore aquaculture industry in developed countries to overcome the competitive advantages of the developing world, and Asia, with its abundant expertise, may well become the center for any major growth in this area.

With regard to low trophic organisms, it is presently difficult to envisage many instances where their production offshore appears viable or advisable. That is not to say that this situation will persist indefinitely. Should offshore finfish production expand and become successfully established on a large scale then technological advances, greater familiarity with working in high energy environments, greater activity in the offshore area and clearer understanding of oceanic characteristics, will undoubtedly prove helpful to the establishment of low trophic operations. Caution should be taken to assess the environmental parameters of offshore sites, and efforts made to gain a fuller understanding of the biological and culture systems requirements of some of the candidate species identified in order that the two can be effectively matched. Such a measured holistic approach is what is truly needed. Importantly that approach also takes into account the human aspects of production as essential if attempts to initiate low trophic offshore aquaculture are to move forward in any meaningful sense.

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- Informant 3, Interview, 11/23/04
- Informant 4, Interview, 11/23/04

- Informant 5, Interview, 11/29/04
- Informant 6, Interview, 11/29/04
- Informants 7 & 8, Interview, 11/29/04
- Informant 9, Interview, 11/30/04
- Informant 10, Interview, 11/30/04
- Informant 11, Interview, 11/30/04
- Informant 12, Interview, 12/8/04
- Informant 13, Interview, 12/9/04
- Informant 14, Interview, 12/10/04
- Informant 15, Phone Interview, 12/15/04
- Informant 16, Phone Interview, 12/17/04
- Informant 17, Personal Communication, 3/5/05
- Informant 18, Phone interview, 5/2/05

APPENDIX 1 A CASE STUDY OF THE DEVELOPMENT OF OFFSHORE AQUACULTURE IN HAWAII

INTRODUCTION

In the Pacific region, Hawaii is at the forefront of US offshore aquaculture development. As such, it offers the best available example of the developmental criteria that offshore aquaculture may require in order to become established. It also provides an opportunity to assess the social and economic effects of offshore development, and any conflicts that may arise from them.

THE RATIONALE FOR DEVELOPING OFFSHORE AQUACULTURE IN HAWAII

Historical factors have significantly influenced the establishment of offshore aquaculture in the state. The foundations of Hawaii's economy were formerly in defense, tourism and plantations. Closure of the majority of its plantations in the 1980's led to an economic crisis for many rural areas, and the need to generate alternative jobs and economic development (Personal Comm. Informant 3).

Accordingly, economic diversification has become a priority for the state, and emphasis is placed on high-tech industries (including aquaculture), which are seen to represent a major growth opportunity. The state's goal is "for aquaculture, including production and services to become a major component of Hawaii's high-tech industry, and a major supplier of jobs and income growth" (DBED&T, 2002, p54).

HAWAII STATE LAW

Commercial offshore aquaculture became possible in Hawaiian state waters in July 1999, following an amendment to state law. Chapter 190D, Hawaii Revised Statutes, was enacted, "allowing greater utilization of Hawaii's ocean resources for research and sustainable commercial development open ocean aquaculture" (DNLN/DOA, 2003, p4).

Extensive dialogue and collaboration between state agencies, entrepreneurs, and research institutions was critical to passing the legislation. This established a framework and process that could be followed by prospective aquaculturists in the future (Personal Comm. Informant 5). The amendment was facilitated and strongly supported by the state Aquaculture Development Program (ADP) (part of the state Department of Agriculture), in cooperation with the Department of Land and Natural Resources (DLNR). Entrepreneurs who later established offshore farms, were key in passing the amendment, as were testimonies from staff at the University of Hawaii (UH) and Oceanic Institute (OI) (Personal Comm. Informant 3).

During this period UH and OI were partners in a demonstration project aimed at assessing the feasibility and environmental impacts of growing moi (*Polydactylus sexfilis*) in marine cages. This effort, the Hawaii Offshore Aquaculture Research Project (HOARP), was also a significant factor in generating interest in, and support for, a change in the law.

As of this writing, 3 leases have been granted: one to Cates International Inc (CII) which farms moi on Oahu: one to Black Pearls Inc (BPI), for pearl oyster grow-out, also on Oahu, and one to BPI's sister company, Kona Blue Water Farms (KBWF) for raising kahala (*Seriola dumerili*) on Hawaii's Big Island.

CATES INTERNATIONAL INC

CII became the first commercial offshore aquaculture operator in the US, after being granted its lease in 2001. The company's owner had been involved in the HOARP as a contractor, providing maintenance and transport with the company Safety Boats Hawaii. The process of applying for a lease and conducting an Environmental Assessment (EA) began in late 1999, and CII commenced production in late 2001.

At present, CII utilizes 4 submerged cages, 2 miles offshore of Ewa Beach, Oahu, to harvest around 8,000lbs of fish a week. At full production, the farm will produce 1,000,000lbs (500 tons) of moi per annum (Personal Comm. Informant 4).

BLACK PEARLS INC

BPI was formed in 1992 with the objective of reestablishing wild stocks of black-lipped pearl oyster (*Pinctada margaritifera*) in Hawaii, and establishing a commercial pearl farm. In August 2001 the DNLR granted BPI a lease for a 75acre growout site in sheltered waters off Honolulu international airport. BPI's original attempts to lease a site for this purpose, beginning in 1995, were crucial to securing the amendment to Hawaii Revised Statutes Chapter 190D that made leasing possible. The lease has yet to be executed, as DNLR's Department of Boating and Ocean Recreation must remove the site from a 700 acre thrill craft area and find another 75 acres for use by thrill craft elsewhere, but production is expected to begin within the next 6 months. (DNLR/DOA, 2003).

KONA BLUE WATER FARMS

KBWF was formed in 2001 as a subsidiary of BPI. It had its lease approved in November 2003, and became a separate limited liability company in 2004. 6 submerged cages for production of kahala will be installed in February 2005, 2,600 feet from shore, close to the Natural Energy Laboratory of Hawaii, Kona. The first harvest will be in July 2005. Production will be 800 tons/year at steady state, the majority of which will be exported for use as kampachi, a form of sushi. All KBWF's hatchery needs will be met by BPI.

OTHER VENTURES

Various other companies have applied for leases, or are interested in submitting applications. Pacific Ocean Ventures is seeking a site off Maui to grow kahala and moi, and another firm is seeking to do the same off the island of Molokai. A tuna farm, Ahi Farms, has submitted permits that would allow it to utilize 2 sites off Waianae, Oahu.

In 2002 Ahi Nui Tuna Farming, submitted plans to utilize 18 surface cages between 1,100 and 3,800 feet from shore, 4.5 miles north of Kawaihae on Hawaii's Big Island. At full production, the farm would have grown out 54,000/year juvenile tuna to a weight of just under 4.5million lbs. The plans were dropped following concerns voiced by members of the public, and the company is said to be investigating alternative locations further offshore (ANTF, 2002).

THE LEASE APPLICATION PROCESS

Leases to conduct aquaculture in state waters are granted by the Board of Land and Natural Resources. Before a lease can be granted applicants must successfully obtain a series of permits. The Land Division of the DLNR must issue a Conservation District Use Application permit, dependent on acceptance of the applicant's draft EA and management plan. The state also requires a National Pollutant Discharge Elimination System permit, issued by the Department of Health's Clean Water Branch. The federal Clean Water Act, administered by the state, requires a Zone of Mixing permit, and Federal government requires a US Department of the Army permit, issued by the Army Corps of Engineers for any activity that alters navigable waters. Various additional permits may also be required, depending on the scope of the operation (KBWF, 2003).

The state Aquaculture Development Program acts as a facilitator and liaison for prospective lessees, and assists with the completion and packaging of the various permit applications. Applying for a lease necessitates an extensive series of meetings with relevant agencies, parties and organizations, and the drafting an EA. The process culminates in a public hearing, the results of which may affect the final decision on whether to grant the lease.

Leasing costs are calculated by maritime appraisers, and are comprised of a flat fee based on the volume of water occupied by the farm, and a percentage of gross profit in the region of 1% - 1.5%. 80% of these proceeds go to a fisheries and aquaculture development fund, with the remaining 20% going to the Office of Hawaiian Affairs.

THE ROLE OF ACADEMIC INSTITUTIONS

There are several institutions in Hawaii conducting oceanic, biological and aquaculture research, principle among them, the Oceanic Institute and the University of Hawaii, which is a Sea Grant university and houses the Institute of Marine Biology and the Pacific Aquaculture and Coastal Resources Center. The availability of this level of infrastructure and academic support has been very important for enabling research and development and creating opportunities for collaboration with the private sector.

INVESTMENT

Given its early stage of development, Hawaii's offshore aquaculture industry finds it extremely difficult to attract investment from financial institutions. As one informant put it, "banks laugh at you." This means that investment is almost exclusively in the form of risk capital from federal government and private sources, the state having no budget for direct investment in offshore aquaculture (Personal Comm. Informant 3).

A state initiative; the high technology business investment tax credit, which "provides companies that invest in qualified high technology businesses in Hawaii with a 100 percent tax credit up to \$2 million over five years," has encouraged some private investment (High Tech Hawaii 2004). KBWF received \$4million in October 2004 as a result of the scheme which Informant 5 described as, "helpful, though not an essential prerequisite [to private investment]."

The vast majority of risk capital and other investments in Hawaiian offshore aquaculture originate from various federal programs funded by the Department of Commerce (DOC). Informant 3 tentatively estimated the total average annual level of investment at \$3million, of which up to 75-80% originated from DOC (the remainder coming from private sources and institutions such as OI). This sum is directed primarily at hatcheries and environmental monitoring, and was described as crucial to the industry's development.

STATED BENEFITS

The principle expected economic benefit of Hawaiian offshore aquaculture, as suggested by informant 3, is increased export revenue for the state. Hawaiian exports are worth a relatively meager \$350million annually. Based on a projection of 10 farms producing 1million lbs/year, the informant estimated that a direct economic impact of \$100million a year would be generated. Using these figures, and assuming an economic multiplier of 2.1, the informant calculated that the total economic impact of 10 farms would be over \$200million per annum. It was felt however that, "the state would be doing very well to have 10 new farms in 10 years."

Informant 4 put the economic impact generated by 10 farms at \$60million and felt that there might be 10 leases granted over the next 10 years, of which only 4-5 would survive as businesses. Informant 5 felt that there might be 8 farms in operation a decade from now, "perhaps 2 on each of the major islands."

It was estimated that a farm with 1,000,000lbs/annum capacity and its own hatchery, would directly employ between 10 and 20 staff. Of these, 5-10 would work onshore, and 5-10 offshore. The primary employment for a 20-person farm might include 10 divers, 5 hatchery staff, several boat operators, a manager, a marketing person and an accountant. Given that offshore farmers must be professional divers and accomplished at handling boats, feeding the fish and cleaning the nets underwater, much of this work would be skilled, as would work in the hatchery (Personal Comm. Informant 3).

CII currently employs 7 people: 5 operators and 2 administrative staff. Once a hatchery has been added it should employ around 12 people, with half or more of these positions being “high-tech” (employing staff who will have been educated to at least Master’s degree level) (Personal Comm. Informant 4).

KBWF provides 6 fulltime positions including project management and administration. Labor and salaries comprise nearly 25% of its recurrent steady state costs. Hatchery work, although contracted out to BPI, employs a further 3 fulltime staff. At full production, the company believes it will offer 10 fulltime positions which will provide alternative employment for fishermen displaced by tightening regulation of bottom fishing and long-lining. Assuming a price per pound of \$3.50 for fresh product, the farm’s turnover will be \$2,770,000 per annum (KBWF, 2003).

A multiplier of 2 for secondary employment was assumed by informant 3, meaning that a farm primarily employing 20 people would create 40 secondary jobs comprised of; labor, equipment repair, fish processing, handling, marketing, transport on and off the water, and accounting.

Informant 4 stated that at least 20 people were involved in the processing of fish from CII (though not exclusively employed for this purpose). It was also noted that 6,000 consumers a week on Hawaii benefit by eating moi that would otherwise have been unavailable, and that a least 3 staff are required to serve a meal in a restaurant. The vast majority of CII’s fish are sold and eaten in Hawaii through the restaurant trade. The company exports around 400lbs/week to California.

Informants estimated that by 2025 the number of staff directly employed by offshore aquaculture would be 115, of which more than half could be classed as skilled. Coupled to a multiplier of 2 for secondary semi-skilled or unskilled employment the total number of jobs stemming from offshore aquaculture would be somewhere in the region of 345, of which perhaps a third might be considered skilled or professional.

Informants 3 and 4 noted that operators would generally seek to automate processes such as feeding, harvesting, monitoring and net cleaning wherever possible. They foresaw a tradeoff however, believing that increased automation would lead to more efficient management, and hence, the production of greater volumes of fish for export, thereby compensating for the possible decline in primary employment.

Informant 5 saw the “more sustainable use of marine resources” as one of the major benefits accruing from offshore fish production, believing that existing wild capture fisheries are at risk of extinction. KBWF’s EA states that fish farming will diversify the economic base of the islands, offering immunity to fluctuations in the tourist industry as well as strengthening maritime support industries. The farm would also increase Hawaii’s profile as a site for innovative ocean aquaculture and offer opportunities for training and extension work (KBWF, 2003).

CONFLICTS

KBWF and CII have garnered little public censure. Informant 5 noted that there were no objections at KBWF’s lease hearing, and believed this was because the company took 3 years to process its application and was able to address the community’s concerns and gain acceptance during this period.

By contrast, Ahi Nui Tuna Farming (ANTF) was forced to revise its plans significantly, following the rapid and effective mobilization of community groups against it. Officially, ANTF is said to be seeking an alternative site for its operation, although several informants expressed the belief that it was no longer doing so. ANTF’s failure to obtain a lease was viewed by informants 4, 7 and 9, as being exacerbated by the company’s foreign ownership and limited understanding of Hawaiian culture.

2 key groups were identified as having the greatest antipathy to the project: Native Hawaiian fishers, and a wealthy homeowners association representing properties overlooking the proposed site (Personal Comm. Informant 6).

Members of Kohala Fishermen's Association (KFA), a largely Native Hawaiian group, voiced concern that ANTF had no roots in the area, and hence no real stake in maintaining the health of the sea for future generations. Examples were cited in which developers had caused irreparable damage to traditionally utilized natural resources and excluded Native Hawaiians, with the result that it was no longer possible to participate in and pass on ancient cultural practices to future generations. Overall, there was very strong feeling that the owners of ANTF were not accountable to the land and would disrupt its balance. It was not believed that the farm would have benefited Native Hawaiians in any significant manner, and the project was felt to be an unacceptably large unknown quantity in terms of environmental risk (Personal Comm. Informants 7 and 8).

Informants 3, 4, and 5 all stated that offshore aquaculture could not proceed if the local community objected to it, and viewed ANTF's decision to find an alternative location as evidence that the lease application process effectively served the public interest. By contrast, informants 6 and 7 felt that the lease application process excluded Native Hawaiian input. Many members of that community lacked extensive formal education, and found the process they had to go through to make their opinions known intimidating. This resulted in an institutional bias that acted against their interests. Had access to legal advice not been available, KFA would have been unable to file papers lodging a contested case, an action seen as pivotal in influencing the outcome of ANTF's decision to move the farm. Public input into the lease application process was only seen to be effective for people possessing elevated educational and social status.

CII and KBWF do not compete with any existing fishery (there is no commercial moi fishery and kahala are not eaten in Hawaii as they are believed to be contaminated with worms that cause ciguatera poisoning). They are therefore unlikely to displace any fishers. By contrast, it was felt that by competing for tuna brood stock, ANTF would damage the small artesian ikashibi fishery, which captures tuna at night with hand lines and, to a lesser extent, the sport fishery. Additionally, it was felt that baitfish for fattening the tuna might be sourced locally, also impacting the commercial and sport fisheries (Personal Comm. Informant 6).

It was not believed that the farm would offer adequate or viable alternative employment for displaced fishermen and that the majority of positions it offered would be \$12/hr seasonal labor, of which there is already a surplus in Hawaii. It was also thought that by impacting the view plane, the farm would discourage construction of "million dollar homes" in the area, thereby negatively impacting the Big Island's economy (Personal Comm. Informant 6). Informants 6 & 7 noted that any offshore operation must land its catch. This requires use of a port. The harbor at Kawaihae was said to be "at capacity," and it was felt that it would rapidly have become a contested location, "all the way down to access to the boat ramp and arguments over car parking space."

Owners of small 'eco-businesses' also voiced concerns about how they would be impacted in the case of unforeseen environmental consequences, fearing that not only their business, but that of large resorts, would be irreparably damaged if the health of nearby reefs were compromised (Personal Comm. Informants 9 and 11).

SUMMARY

Several factors have been critical to the establishment of Hawaii's fledgling offshore aquaculture industry. These are as follows:

- The availability of federal risk capital, and political and bureaucratic support from the state and its agencies.

- Entrepreneurial commitment, and the existence of extensive academic infrastructure and a highly visible demonstration project.
- The collaboration of all these actors both, in changing ocean-leasing law, and in prior and subsequent research efforts.

The major anticipated benefits to the state of Hawaii are an increase in export revenues and diversification of the rural economy. Modest job creation is likely to occur, perhaps several hundred primary and secondary positions being generated over the next decade. Of these, up to one third may be skilled or professional.

Locally established operators deploying several submerged cages have met with little public resistance. Significant user conflicts with fishermen, homeowners, small businesses and Native Hawaiians, have been evident in the case of industrial scale operations, and have so far prevented this form of development.

APPENDIX 2

A CASE STUDY OF OFFSHORE BLUE MUSSEL AQUACULTURE IN NEW ENGLAND

INTRODUCTION

The University of New Hampshire's open ocean aquaculture project arose as a response to long-term fishing stock collapses and subsequent economic crisis in the Northern Atlantic coastal region. The project, which began in 1997, seeks to stimulate aquaculture development through increasing seafood production while favorably impacting employment, economic and community development (<http://www.ooa.unh.edu>). While the project encompasses research and development on a number of high trophic finfish (e.g., cod, haddock, summer flounder, halibut) we will focus exclusively on blue mussel (*Mytilus edulis*) culture, as it is the most applicable species for purposes of this report. Notably, the OOA project has advanced this culture system into the commercial realm by involving two fishermen's cooperatives in mussel grow out. Importantly, UNH project staff assessed public attitudes early in the project's inception among various social groups (Robertson and Carlsen 2003). This led to distinct targeting and outreach efforts to near shore commercial fisher coops as beneficiaries for embarking on application of commercial blue mussel culture.

BLUE MUSSEL CULTURE

Mussel culture has been long established in a number of countries in both the developed and developing world. In the Northeast Atlantic region, Prince Edward Island is considered the leading culture area in terms of mussel production and established market relations (Hoagland et al., 2003). Blue mussel culture generally begins with seed collection in selected areas using ropes suspended from surface rafts. Langan and Horton (2004) also reported that seed settlement occurred on the actual long lines used for UNH's offshore pilot project. Once seed reaches a minimum size juvenile stock is sorted, graded and placed in tube sacks where they are attached to long lines for grow out purposes. In the UNH demonstration project 120 meter suspended lines are used and anchored by 40 meter sections on each end (Personal Comm. Informant 15). This system was adopted from New Zealand's experience with green-lip mussels (Hoagland et al. 2003). The demonstration project tested a number of materials used to suspend the long line culture system. Researcher's noted that blue mussel grew rapidly (after 14 months from stocking) and offered a better quality product than near shore systems. Notably, not all mussel culture in Eastern North America displays uniform growth and product quality (Hoagland et al., 2003). Harvesting mussels in this case requires some modifications to fishing vessels by adding a custom-designed hydraulic starwheel, and aft idler wheel, and a stationary boom for vertical lifting (Langan and Horton 2004). Investment costs are modest. Once ashore mussels are cleaned, de-clumped and graded for shipment to local markets found along the Eastern Coast. Cultured mussels bring a better price than those dredged from wild beds. Markets have grown for mussels over the past two decades and New England mussels are popular along the East Coast as well as select areas inland (Hoagland et al. 2003).

PERMITTING

The actual UNH blue mussel demonstration project took place in New Hampshire State waters. The permit process had to go through a two-year sequence involving both Federal and State agencies. Permitting started with the Army Corps of Engineers, the Environmental Protection Agency and the National Marine Fisheries Service (see Hoagland et al., 2003). The latter concerns pertained to whale migratory routes, so a biological assessment (BA) was done to account for risk involving entanglement by whales and turtles (Personal Comm. Informant 15). At the State level, a permit must be obtained from the New Hampshire Fish and Game Department. This process undertaken by UNH researchers was the first of its kind and involved a number of meetings as well as 3 public hearings. No significant objections to the project (which also has a finfish component) were raised. The New England based Conservation Law Foundation however, has opposed the "privatization of public waters without a national policy debate" and successfully

stopped an earlier proposed salmon farm offshore operation in the EEZ (Hoagland et al., 2003). It remains to be seen whether further litigation will be forthcoming from legal groups opposed to privatization efforts occurring in public waters. Overall, the blue mussel experience enabled UNH to begin transfer of technology to 2 fishermen’s cooperatives and potentially other prospective aquaculturists in the area. As of this writing two farms run by individual cooperative members involving 5 long lines apiece are in operation. The cooperative arrangement was used due to the small farm size and the ability to share post-harvest grading and sorting machines owned by the cooperative.

ECONOMIC VIABILITY

Hoagland et al., (2003) undertook extensive macro market analysis and they cover market structure, industrial organization, regulations, consumer preferences, economies of scale and environmental risks associated with mussel culture in the region. They also provide a business plan outline for potential investors. Included in this plan outline are production factors: site and permitting, technology and scale of operations, vessel operations, spat collection and scheduling. The second part of the report pertains to processing, marketing and distribution. At present, the blue mussel culture is envisioned as a part-time supplement to commercial fishing (Personal Comm. Informant 15). As such, some adjustments must be made to the fishing vessel. For farming purposes, the UNH-coop venture involves two individuals tending 5 long-lines each. One hundred and twenty five lines would be considered a large-scale operation involving an investment of approximately 1.2 million dollars (Hoagland et al., 2003). Production per line amounts to an average of six tons per line. Break-even price for a profitable operation is estimated to be 0.65-.80 cents per pound of raw mussels (shell on). A key economic determinant for achieving economies of scale however for offshore mussel culture pertains to:

- The use of a customized vessel for harvesting and processing raw product, and
- Adding value to harvested product in the post-harvest phases

Green-lip mussel culture in New Zealand currently is viewed as the model culture system in the world. In New Zealand, mussel harvest vessels have been exclusively designed for this sole purpose (Personal Comm. Informant 18). The New England pilot project however, began with the idea of providing commercial fishermen an opportunity to remain “on the water” during times when vessels would be otherwise idle. As such, blue mussel culture is presently seen as a supplementary activity to commercial fishing (Personal Comm. Informants 15&18). It was estimated that a fully operational offshore blue mussel farm would require between one and million dollars intial investment (Personal Comm. Informant 18). Finally, adding value to raw mussels remains a key dimension in establishing overall economic viability in the market. In an increasingly competitive global mussel market where New Zealand product is the most highly valued, processing, freezing, packaging and other post-harvest inroads need to be made, as the product in fresh form holds a limited market life (Personal Comm. Informant 18).

ASSESSMENT

The New England blue mussel demonstration project offers a number of valuable lessons for purposes of this report. Unlike other speculative offshore efforts detailed in this report, UNH researchers conducted, early on, a communications campaign and focused socio-economic research that led to the research results entering into applied commercial activity by a group normally opposed to such interference in their traditional occupation. While only consisting of five long lines each, these early farming efforts require further monitoring as to the manifestation of social and economic benefits as envisioned by project planners. That said, offshore blue mussel culture faces further development obstacles in terms of achieving sufficient economies of scale to successfully compete with established industries in Prince Edward Island and other parts of the world. While we surmise that the market could continue to bear increased mussel production in

the short-run, achieving sufficient economies of scale will require tradeoffs between risk benefits and costs. In the final analysis, the activity becomes more entrepreneurial in scope involving corporate organization, financial resources, and post-harvest technology development in order to remain viable. While most of our informants were “guardedly optimistic” about future prospects, economic and biological constraints are likely to limit any major offshore blue mussel aquaculture effort to only the most efficient operations in the long-run. At the same time, blue mussel culture has a definite interim role to play in integrated coastal zone management schemes, and in the short to medium term, offer commercial fishermen an opportunity to adjust to severe restrictions placed on the capture fisheries.

BIVALVE MARKET STUDY IN PACIFIC MEXICO

*Twelfth Work Plan, Economic/Risk Assessment & Social Impacts 6 (12ERA6)
Final Report
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ABSTRACT

This research is part of a larger effort to elucidate relationships between human health, water resources and aquaculture status and development in the States of Sinaloa and Nayarit, Pacific Mexico Coast. Oyster culture (*Crassostrea corteziensis* and *C. gigas*) is an important industry for small-holder aquaculture along the Pacific Mexico Coast, but little work has been done to assess its economic value nor assist producers in improving market opportunities. A market study was conducted for oysters grown by social (cooperatives) groups of farmers in Bahía Santa María (BSM), Sinaloa, México, as part of a multi-activity effort conducted with the beneficiaries in order to help them to successfully produce and commercialize their oyster production. This study provides them with market information from the demand side, including consumer preferences.

The market study focused on information from three sources: a) local demand near production sites; b) regional main tourism destinations places such as Mazatlán (State of Sinaloa), Puerto Vallarta (State of Nayarit) and Los Cabos (State of Baja California Sur), whose restaurants and hotels might be an important source of demand; and c) national wholesale markets, specifically two of the most important seafood markets in Mexico, La Nueva Viga (Mexico City) and Zapopan (Jalisco). For the first case, on-site personal interviews were conducted with 15 potential sellers in towns and cities close to BSM. This market is considered the most feasible, immediate choice for the producers, considering their projected production capabilities. For the second phase of the study a mail survey was conducted, sending in total 86 questionnaires to individual restaurants, or hotel-restaurants in the three cities which are tourism destinations, but the response rate was very low (2) and not much could be analyzed from them. For the final source of information, secondary-source information from wholesale markets was gathered and analyzed to determine the feasibility of producer's entry into larger markets.

The results show that selling directly to local buyers (restaurants and mobile kiosk "carreta" owners) is the best marketing strategy to follow for the stakeholders, considering their current low

production capacities, but mainly due to the characteristics of this local market. The study revealed preferences for the local (*Crassostrea cortesiensis*) oyster over *C. gigas*, a market window for product with consistent year-round supply; preference for larger sizes and which is perceived as safe for human consumption. The stakeholders are advised to take advantage of a possible 0.50-1.00 peso increase in price per piece that buyers will pay when the said characteristics are met.

In sum, stakeholders from this project may consider taking a price premium offer by survey respondents from local markets by delivering a high quality, larger sized oyster with safety guarantees. With products that include the said characteristics, a long-term commercial relationship that is based on trust and personal communications can then be established with buyers. The timing may be right for the stakeholders to develop markets and buyer-seller relationships in the markets surveyed based on one-on-one interviews, which guarantees the price premium offered by the buyers. In a few years more there will be more products on the market, and the price elasticity of demand may turn negative. Finally, wholesale markets are not recommended to the stakeholders, since the local market is large enough to absorb current production, but also due to a reduced margin profit in La Viga and Zapopan markets. The stakeholders would find it very difficult to sustain a high-volume supply of oyster, which is required to compete for these markets.

INTRODUCTION

This work proposes to build on past and current efforts on the Pacific Mexico Coast designed to promote viable aquaculture alternatives other than shrimp mariculture with the goal of optimizing returns and benefits to rural, coastal communities. Shrimp mariculture, the leading form of aquaculture for the Pacific coast of Mexico, is facing catastrophic losses due to disease and falling prices, and is perhaps not always the most ideal form of aquaculture from the perspective of minimizing environmental and social impacts. Previous work conducted by a multi-institutional, international team since 1997 has built a solid foundation for diversification of aquaculture in Pacific Mexico emphasizing the use of native species, particularly those low on the food chain and with low culture technology requirements. Among the leading candidates are bivalves, which are currently cultured and fished extensively along the Gulf of California Coast, with much of the production attributed to wild captured fisheries. However, great potential exists to expand current aquaculture production through strengthening existing operations and developing new species of bivalves for culture.

From the Mexican governments' perspective, specifically that of CONAPESCA (National Aquaculture and Fishery Commission), species diversification is clearly a policy goal to pursue and support. However, feasible alternatives are still being developed, like marine fish culture. Today, available and feasible biotechnologies for species diversification in the country are tilapia and oyster farming (Martínez-Cordero, 2007). In the last three years the Program Alianza para el Campo (Alliance for the Rural Areas), which is the main federal program operated at national level that promotes and supports the development of aquacultural projects, has financed tilapia and oyster projects at different scales of operation in many States. Social groups like cooperatives are usually selected to receive support for oyster farming, and in Sinaloa coastal communities have benefited from this Program. This includes fishermen entering aquacultural activities for the first time, which the Mexican government calls system conversion.

From an historical perspective, shrimp farmers in Bahía Santa María (BSM), Sinaloa, México have been receiving assistance since 2004 by CRC, UAS and PACRC experts in developing a management and development plan for the Bay. Since shrimp farms in this area have suffered of heavy viral diseases outbreaks in latest years that brought about diminishing yields and profits, an important part of the sustainable development plan is to diversify production, and some of the farmers have expressed interest in starting bivalve culture (oyster and hard clam).

Bahía Santa María is located on the Southeastern coast of the Gulf of California, in the State of Sinaloa, and is part of the municipalities of Angostura and Navolato. This Bay is among the 20 lagoon and estuary systems in the Gulf of California that are included in the Carta Nacional de Pesca, meaning that a diagnosis has been carried out due to its relevance for fisheries and aquaculture. In addition to wild shrimp fisheries, there are almost 7,000 hectares of shrimp farms in the tidal flats adjacent to the mangrove forest of BSM, which borders much of the shore and islands (Robadue and Rubinoff, 2003).

During the past two years of collaborative work, bivalves (clams, oysters, pen shells, etc) were identified as the culture candidates with the most potential to offer an alternative to shrimp farming for coastal communities of Mexico given the extensive areas of wetlands and tidal flats (Haws, 2005). Shellfish culture also offers more opportunities for participation of women and other marginalized groups due to their ease of culture and low input requirements. Bivalves however, are particularly demanding in the area of sanitation and food quality due to their filter feeding habitats which can lead to accumulation of bacteria, viruses and toxic products, tendency to bio-accumulate heavy metals and sensitivity to post-harvest contamination. Resolving water quality, handling, processing, marketing and transportation issues related to production of safe bivalves will not only help improve the benefits and reduce risks associated with this form of culture, but will also serve as a model for improved sanitation for other species targeted for development such as finfish.

A key problem encountered to date is that there is little information on marketing channels, opportunities, prices and consumer preferences for bivalves, of which there are literally hundred of species that are or could be culture candidates. There is also a lack of clarity as to the regulatory nature of this field and the requirements for implementation of existing regulations. While the coastal communities involved in this work in Sinaloa are surrounded by major cities (e.g. Culiacan), tourist destinations (Los Cabos, Puerto Vallarta, Mazatlan) and are close enough to the United States to export bivalves, more information is needed on the economics and markets to inform current and future efforts.

Market demand is one of the key issues for species selection in aquaculture. Per capita consumption of seafood in Mexico is very low, compared with many countries in the world. In 2002 reached 11.5 kg/person, and specifically oyster consumption was 0.49 kg/person. On the supply side, total oyster production in Mexico grew from 25,847 tons in 1993 to 50,219 tons in 2003 (Figure 1). States in the Gulf of Mexico (Tabasco, Veracruz and Campeche) share is almost 85% national production. Most of the said oyster production comes from aquaculture activities, which includes “pesquerías acuaculturales” (re-stocking). Traditionally oyster production in Sinaloa has not been as attractive to investment as shrimp production, but shrimp farmers are turning to bivalves and marine fish culture as a strategy to reduce risk in their operations.

To date, little work for either production or economic impacts has been done within the various Mexican states to assess the progress of the oyster industry in the said states. Moreover, little has been done on assisting the farmers in market identification and assistance in market penetration strategies. The only assistance farmers received are on sanitary issues, provided by the state aquaculture health committee (Comité Estatal de Sanidad Acuicola de Sinaloa CESASIN = Sinaloa State Aquaculture Health Committee), part of the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA = National Service for Agrifood Health, Safety and Quality).

The oyster farming industry in the State of Sinaloa has not grown significantly in latest years. In particular, producers in BSM are incumbents in this activity, and in order to be successful in their projects (meaning to be able to maintain them over time), the market side is certainly the critical aspect to solve. Although it is not believed that the Sinaloa’s oyster market is saturated, it is also

true that these new projects have to find new market opportunities, or differentiate their product in order to successfully compete.

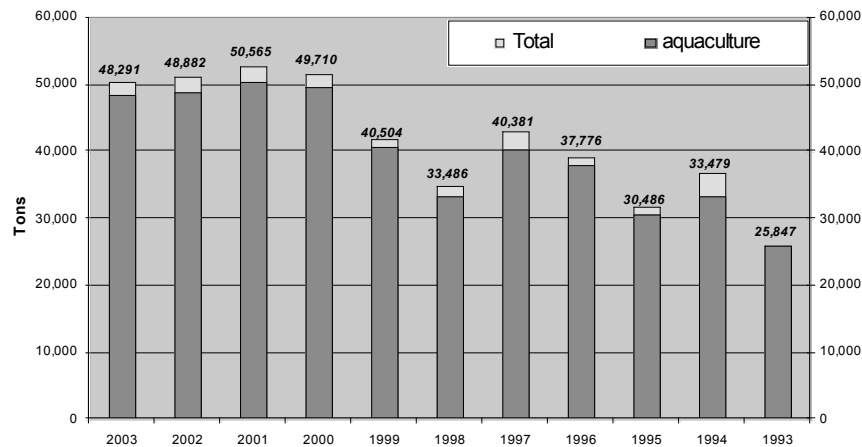


Figure 1. Oyster production in Mexico in the period 1993-2003, total and aquaculture. (Figure above each bar is oyster annual production by aquaculture)

The main objectives of this study are:

- a) identify opportunities for the marketing of oyster from BSM cooperatives;
- b) identify product characteristics which are most important to the successful marketing and sale of oysters.

A second, general objective of this work is to identify regulatory bottlenecks in harvesting and transporting bivalves in Mexico. Current regulations in place are included as an appendix. Additionally, marketing training materials and an Aquanews article were produced.

Specific objectives of this study are:

1. To identify local/regional market opportunities around BSM by personal interviews.
2. To conduct a oyster market preference mail survey to hotel and restaurants at tourist destinations.
3. Conduct an overview of the oyster wholesale market in Mexico using secondary sources.

METHODS AND MATERIALS

The market study focused on information from three sources: a) local demand; b) regional main tourist destination such as Mazatlán (State of Sinaloa), Puerto Vallarta (State of Nayarit) and Los Cabos (State of Baja California Sur), whose restaurants and hotels might be an important source of demand; and c) national wholesale markets specifically La Nueva Viga (Mexico City) and Zapopan (Jalisco) seafood markets, which are the two most important in the country. For the first case, on-site personal interviews were conducted with 15 potential shellfish sellers in towns and cities close to BSM. This market is considered the most feasible choice for the producers, considering their projected production capabilities. For the second phase of the study a mail survey was conducted, sending in total 86 questionnaires to individual restaurants, or hotel-restaurants in the three cities, but the replies were very low (2) and not much can be analyzed from them. For the final phase, secondary-source information was gathered and analyzed from different sources in the country.

The methodological approach is typical for this kind of studies, as reported by Engle and Quagraine, 2006; Hague 2005, Harrington 2005. The market identification part of the work consisted of two phases. In phase one, potential customers were identified, focus interview conducted, and the survey designed. Tourism directories were used to locate parties that are currently using and/or parties that may be interested in purchasing live seafood for their business. The tourism industry in the northwestern region of Mexico is growing, and is characterized by high-income visitors, who sustain a big number of seafood restaurants. Further, a subset of the identified potential respondents will be interviewed in person to help focus on the most important attributes that a live seafood buyer favors.

At the same time, local consumers in local, smaller markets weren't neglected. Although the average Mexican citizen consumes a small amount of seafood annually, bivalves are probably the most demanded segment of seafood. Bivalves are well recognized and consumed at the point of sale, either fresh or in cocktails. Therefore current and potential consumption was assessed using surveys in the cities of Guasave and Los Mochis, and other local, smaller population areas. For products like oysters, consumption in these smaller communities can be significant, and when considering the production features of the oyster cooperatives, these might be the preferred marketing choices.

The surveys gathered data to analyze desired product characteristics such as appearance, color, size, species etc. rated by the respondents using a point scale system. Purchase intent (will buy or will not buy) and the willingness-to-pay for different product forms was also determined. Further, general information on other marketing variables such as desired shelf-life, packaging form, mode of delivery, expected volume used, seasonality of demand etc. was also collected.

For the analysis of local markets, a questionnaire was designed (Annex 1, in Spanish) and personally applied to 15 potential sellers in the region of BSM. A potential list of oyster buyers in the region was obtained by telephone and personal survey (Annex 2 with addresses and telephone numbers).

RESULTS AND DISCUSSION

Characterization of local markets

The Mexican consumer of oysters usually prefers to eat them fresh. Depending on the region of the country analyzed, the final selling point is either a small restaurant or a mobile kiosk ("carreta"), typical in coastal areas and also in towns and cities in States like Sinaloa (Fig. 2).



Figure 2. A small open-air seafood restaurant typical of coastal areas and a "carreta", a mobile kiosk that is also common. Cocktails (oyster in a mixture with other fresh seafood like octopus and shrimp), either cold or

hot, are the preferred form of oyster consumption. A smaller segment of consumers like to eat them fresh, on the shell, adding lemon and sauce.

Desired product

Potential buyers of oyster, who are direct sellers to consumers, were asked about their opinions and beliefs regarding a number of possible attributes for oyster product, ranging from supply characteristics to the importance of size in overall assessment of oyster product desirability. Respondents rated ten product attributes on a 1 to 10 scale, where 10 represents a highly desirable or important attribute. Figure 3 summarizes the outcomes:

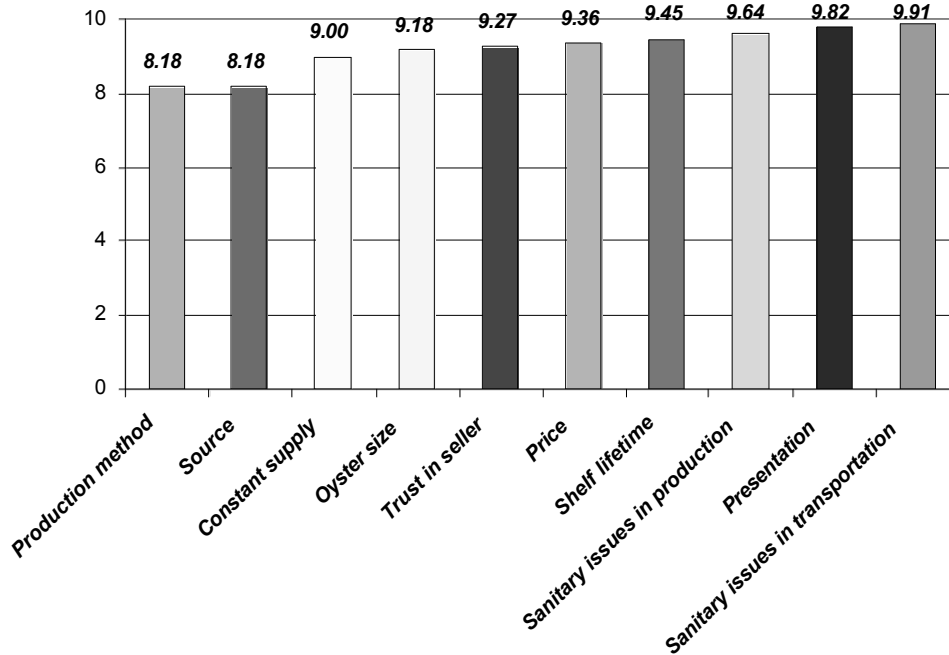


Figure 3. The relative importance of ten attributes to the overall evaluation of product.

Surprisingly, but very promising for the future of the industry, sanitary issues are two of the three most important or desirable attributes for the restaurant owner. Since the product is sold fresh, consumers are concerned about sanitation and the healthfulness of the product being offered. This contradicts a somewhat widely held popular belief that sanitation is not an issue with Mexican consumers. On the other hand, ironically, the least relevant factors are those related with source and production method. Here it is considered that the interviewees don't have much knowledge about the techniques of oyster culture and how they affect quality, and consequently the health of the consumer. Since the top priorities are health-related, source and production method should have been at the top as well.

Price is not a critical issue, nor an irrelevant one. It seems (later discussed in this report) that price elasticity of demand is positive and inelastic at this moment (Varian, 1992), at least for a small change in product price. According to interviewees' responses, current price can even go a bit up, in order to have access to better oyster, in constant supply, and demand would be the same.

Defining oyster quality

Restaurants and mobile kiosk owners, who are direct sellers to consumers and potential buyers of oysters from the cooperatives's aquacultural projects, were asked about their opinions and beliefs

regarding a number of possible attributes for the oyster product, ranging from supply characteristics to the importance of size in overall assessment of oyster product desirability. Respondents rated the eight product attributes on a scale 1 to 10, where 10 represents a highly desirable or important attribute. Results are shown in Figure 4.

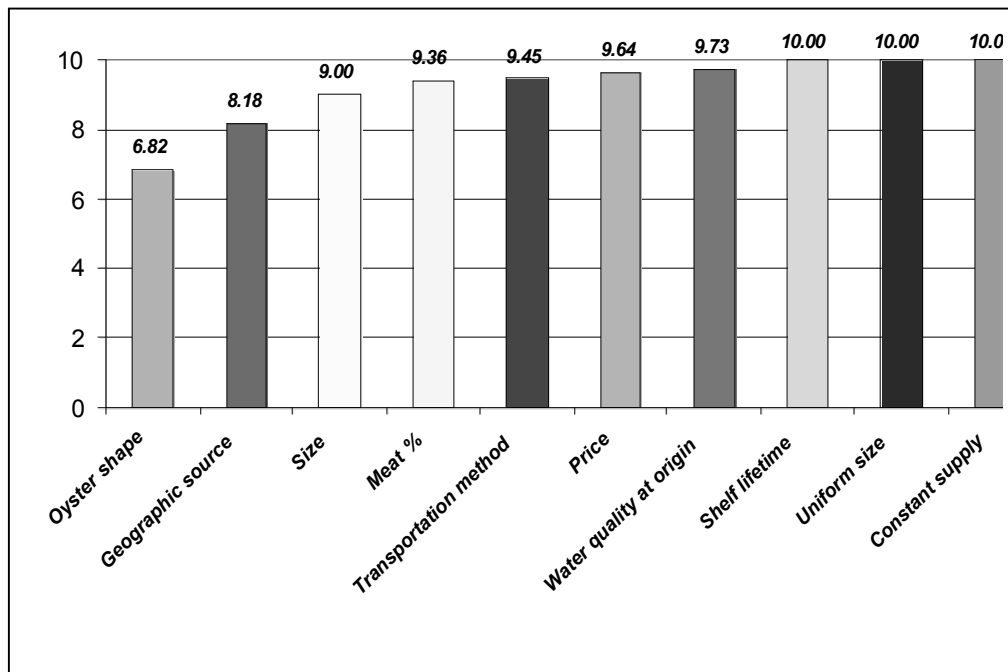


Figure 4. Attributes contributing to perception of oyster quality.

Attributes with highest grades reflect a necessity for a constant supply of product, a good shelf-life (since Mexican consumers eat it fresh mostly) and a uniform size (uniformity of grading). The origin of the product and its form have the least influence on the perception of quality to this sample of buyers. In that sense, it is considered that our clients, potential sellers of oysters, have in their own hands the capability to supply quality product: these three variables are 100% dependant on the production process.

Furthermore, in a continuation of quality definition, the respondents were asked to specifically indicate what would be the “highest quality oyster” for them, which is one with constant annual supply (for 70% of respondents), larger size (61.5%), average shelf-life of 3 days (66.6%), shell-on (100%), “de placer” oyster (*Crassostrea corteziensis*, *C. virginica*) over Japanese oyster (*C. gigas*) (82%), harvested from natural environment (57%), and from the northern Sinaloa State region (54%).

The last three replies are interesting for the analysis: “de placer” (pleasure) oyster is tastier, much smaller and tends to be tough. People who consume “pleasure” oysters buy them by the dozen, or half-dozen, shell-on, and eat it on the shell with lemon and spicy sauce or chile. On the other hand, Japanese oyster (*C. gigas*) is the one selected for cocktails, where it adds bulk, rather than a much richer taste. The consumers and final uses of both types are very different, but the former commands a higher price, therefore its preferred selection.

The fact that harvested from natural environment is preferred over aquacultural product, reflects again that “pleasure” oyster is only supplied from natural growing grounds, whereas the Japanese oyster is mostly from aquaculture. Finally, there is an indication that restaurant and kiosk owners are developing a product preference according to its source. Geographically, the

region analyzed is located in the northern part of the State, which is also the preferred area for the respondents. However, it is interesting that 33% of them said they preferred oysters from southern Sonora, which is the State at the north of Sinaloa. They are referring in this case to several oyster aquacultural projects located in that region, who supply constant, good-quality product (personal interviews).

Product placement

Product channel or placement indicates the routes by which the product will be moved into the market and how this is done, and its distribution. A placement strategy has to be set in case the oyster producers will be the ones directly selling their products, mainly if their production capacity allows them to target a particular franchise or retail outlet.

About half the interviewers indicated sourcing the oysters from distributors. This is certainly a surprising result since the surveyed restaurant are not big, in addition, it is known in the region that bivalve producers usually sell their product. For those few respondents offering both Japanese oyster and “pleasure” oysters, the answer is different depending on the oyster type: the Japanese oyster is usually bought from distributors, whereas the “pleasure” oyster is acquired directly from producers. There is no indication of a big distributor/ wholesaler in the market.

There exist interpersonal and trust-based relationships that come into play and have a significant role. For most of the respondents, reliability of the oyster supplier is very important, and most of them stay loyal to a supplier rather than shifting among them. Figures 5a and b give indication of the length of respondents’ commercial relationships with their current oyster suppliers. Half of the respondents have been working with the main supplier for more than three years, and an additional 27% has 1-3 yrs of experience with a given supplier.

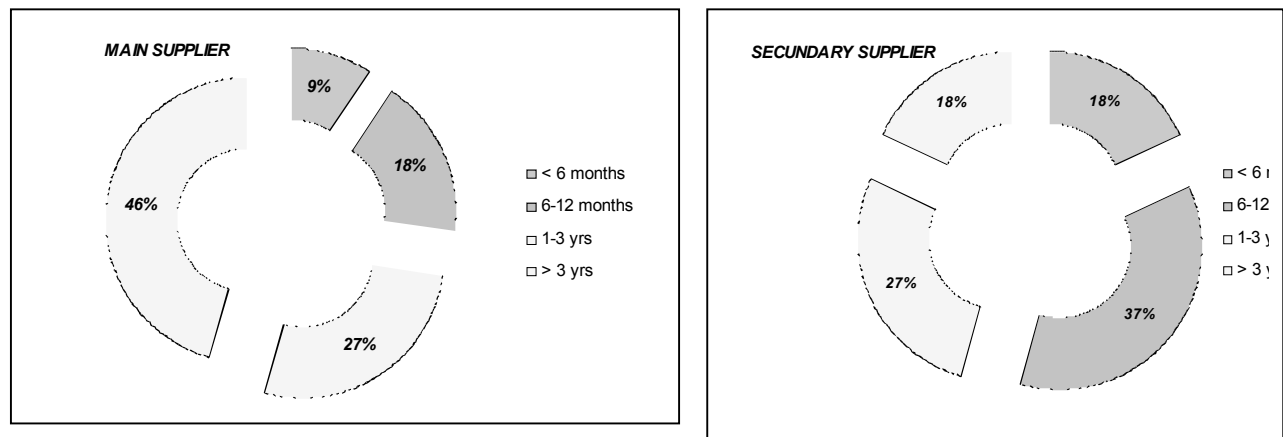


Figure 5a and b. Loyalty and trust: length of commercial relationships with oyster suppliers.

The story of the secondary supplier is different, and only 46% of the customs have stayed with the same supplier for 1-3 yrs or more. Secondary suppliers come into play mainly when the primary supplier is short of product for some unexpected reason, or secondary suppliers may play some during the low season. Respondents stated that during the peak of the hot season (July-September) oysters are difficult to acquire, and health-related issues are critical. It is well known among the common citizen in the region that this season of the year is of high-risk for bivalves consumption, since shelf-life is reduced. When questioned about supply problems, the respondents have a wide variety of responses: some of them said there is no such supply problem at all, while others said there is a shortage even longer than July-September. One of them conferred his expectations that with aquacultural product, this uncertainty would vanish and a stable, health-safe supply will be guaranteed.

Getting product to market quickly appears to have an important role. Most of the respondents (62%) exhibit strong preference for frequent product delivery patterns (2-3 times a week), which by the way is not guaranteed with the current supply, indicating a market window for future projects. 20% of them would like to have daily delivery, which is considered very difficult to achieve. These preferences also have a seasonality component: during cold season there is no need for such a frequent supply, considering the 78% of respondents that weekly supplies are enough. Finally, 100% of the respondents strongly agree with the perception that the market for oysters is growing in their city or region.

How well the restaurant and tray owners know their customers' preferences is key for their business success and provides important insight of the market characteristics and opportunities. Figures 6a-f indicate final consumer preferences, obtained from owners' agreement (or disagreement) with specific questions. The results confirm that the market for fresh, shell-on oyster is the only one in the region. 73% of them also agree that harvesting time is critical to the client, for health issues. However, there are mixed responses regarding to how relevant geographical location and the source of the oyster is. The respondents also strongly indicate (91%) that price is relevant to their customers.

Price

Consumer's price response is always important to assess in market analyses. As shown in Figure 3, price is not one of the top oyster attributes for restaurant and kiosk owners, nor does it significantly define quality. However, the relevance score for price is above 9, which indicates that it still has a very important role in the purchasing decision-making process. On the other hand, all respondents consider that price is important to their clients, that is, to the final consumer (Fig 6b).

Current selling price fluctuates depending on seasonality and type of oyster, from \$3.00 to 4.50 peso/ piece. All the respondents agree that they would accept a small price increment in order to have a constant, higher quality product (Fig. 7), with the majority considering as feasible increments from \$ 0.50 up to 1.00 peso per piece. At the time this research was conducted, the peso to U.S. dollar exchange rate was 10.82 pesos/ dollar, making the U.S. dollar price to be \$0.28-0.42/ piece with a possible price increment of \$0.05-0.09/ piece.

It is considered that in the current price range of \$3.00-4.50 peso/ piece, oyster price elasticity of demand is positive and inelastic. Varian (1992) mentions that the demand for a good is relatively inelastic when the quantity demanded does not change much with the price change. But price elasticity of demand is rarely constant throughout the ranges of quantity demanded and price. For the case of oysters in this market analysis, it is considered that the threshold is \$5.50/ piece, above which demand would become elastic. It is important to underline that this observations are for the Japanese giant oyster *C. gigas*, which is the species selected by the cooperatives for their aquacultural projects. "Pleasure" oysters might have a very different price elasticity of demand, which was not analyzed in this report since the focus is given to the species and production characteristics of the cooperatives projects.

Degree of substitution is always important to assess, mainly for these new projects that are looking to determine a successful strategy to enter a market with many years of operation, which is used to a wild fishery product, and with the customers also following consumption trends and practices for many years. In this sense, the survey inquired of the restaurant and kiosk owners about what product is considered to compete with oysters in their menus. The totality of replies identified clams and "pata de mula" ("grand ark" *Anadara grandis*) as the bivalves competing with oysters mainly through price: these two bivalves are bought at \$0.50 to 1.00/ piece, again with variability depending on seasonality and supply. Demand is not as high as for oysters, though.

Compared to oysters, the survey also inquired about what other seafood products are in greater demand at these points of consumption. Repliers indicate fish, shrimp and octopus. However, in the traditional Mexican consumer's preferences, these latter products are not oyster substitutes.

Characterization of potential wholesale markets: Guadalajara and Mexico City

Wholesalers generally perform the functions of purchasing, transporting, assembling, storing, and distributing (Engle and Quagraine, 2006). In this perspective, it can be considered that wholesale marketing improves efficiency in the distribution system and reduces cost. However, the

My clients prefer to consume oyster produced in the vicinity or a close region

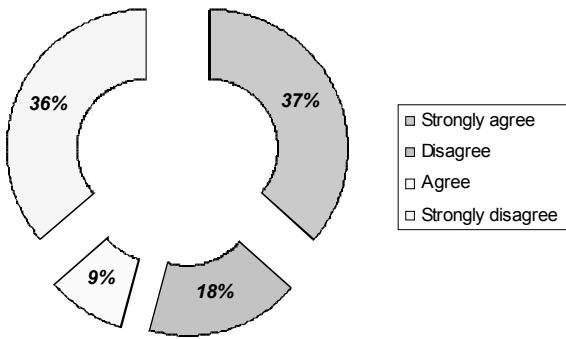


Figure 6a

Oyster price is important to my clients

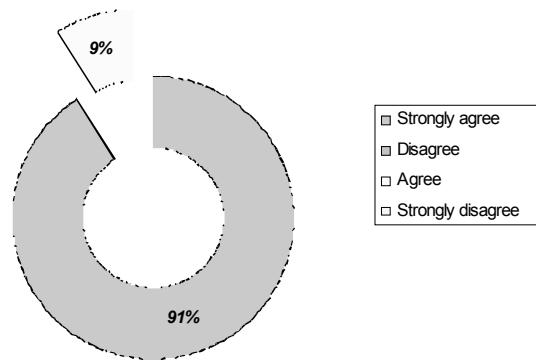


Figure 6b

Geographical location of the aquacultural project is relevant to my clients

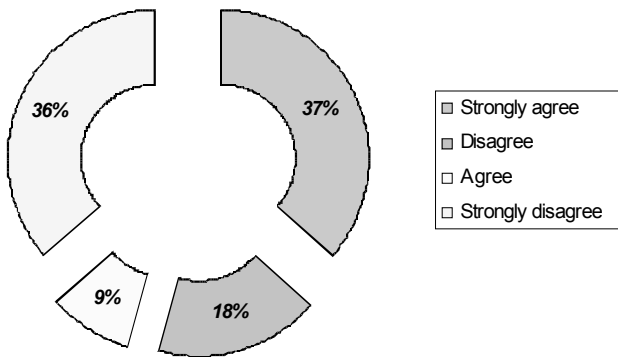


Figure 6c

My clients prefer live, shell-on oyster

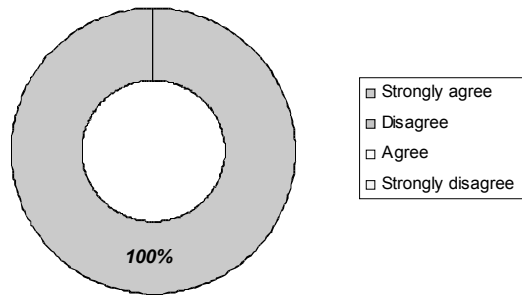


Figure 6d

Knowing oyster rearing and harvesting date is important to my clients

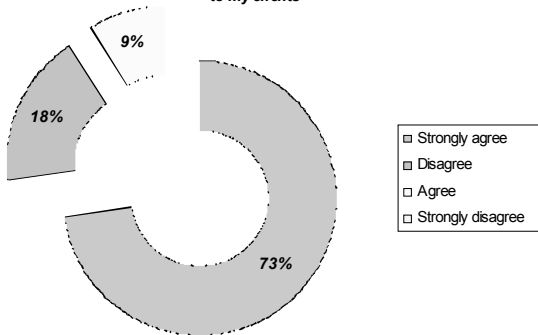


Figure 6e

My clients prefer processed oyster

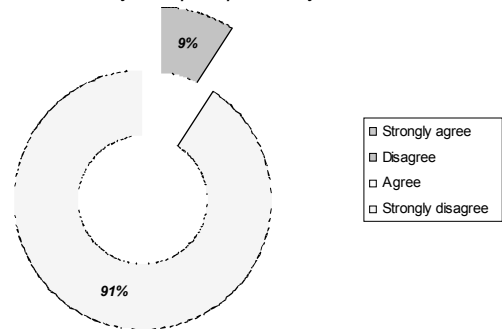


Figure 6f

Figure 6a-f. Final consumers' revealed preferences for oyster, according to restaurant and kiosk owners.

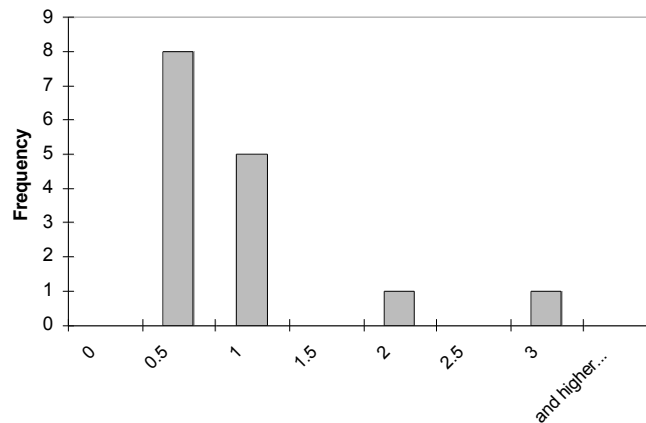


Figure 7. Feasible oyster price increments as a trade-off for a constant, better quality supply.

disadvantages, from the producer's perspective, is that wholesalers are only affordable to large scale producers, and that price is reduced since purchasing orders are in large amounts or bulk. Along the supply chain, wholesalers are able to get volume discounts that individual retail companies are not able to obtain themselves as individuals. The Mexican main wholesale markets for seafood are La Nueva Viga, in Mexico City, and secondly Zapopan, in Guadalajara in the Pacific Coast State of Jalisco.

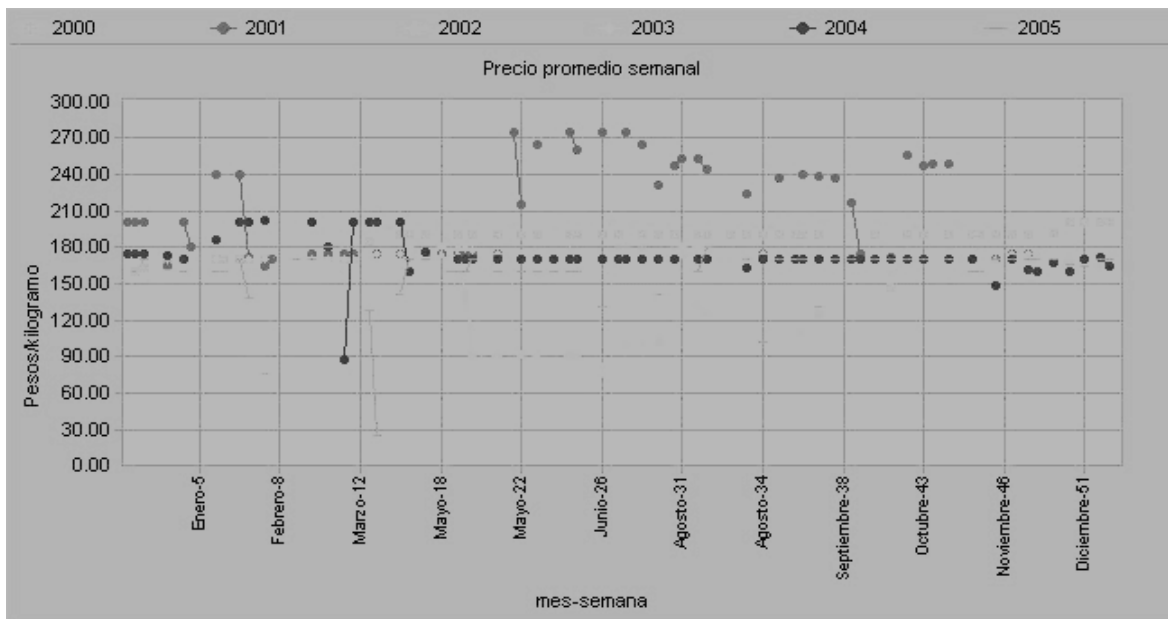
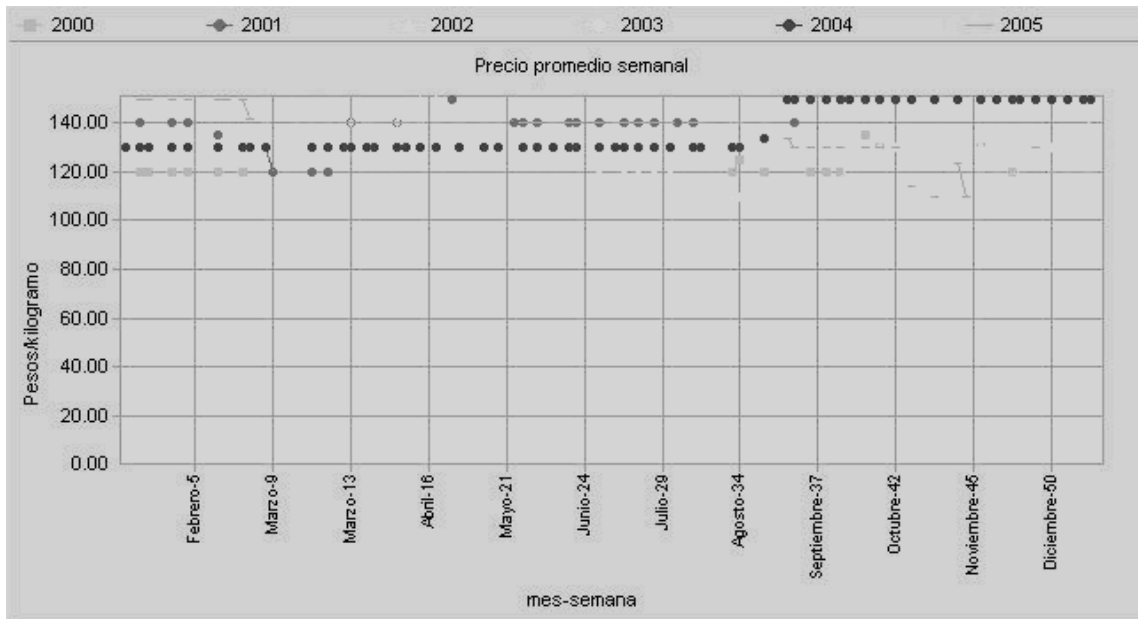
Figures 8a&b show price behaviour of oyster (shell on) in La Nueva Viga and Zapopan respectively. As can be seen, this product achieves a higher price in the Zapopan market, but has been in general terms stable in both markets along the period 2000-2005, with the exception of 2004 when due to a shortage in product prices rose. Current (September 2007) price in La Viga is \$140.00 pesos/kg (there is no information about Zapopan available as yet), which is 12.5% lower compared to September 2006 in the same market.

In a similar manner, but for shell-off oyster, figures 9a&b show historic price behaviour in the same wholesale markets. Figure a depicts the wholesale market of La Nueva Viga, figure b Zapopan, Jalisco. For this product it is clear that the Zapopan market is not a choice. Prices of shell-off oyster are lower compared to shell-on ones in La Viga, and have been slightly falling in the period 2000-2005. Current (september 2007) price in La Viga is \$100.00 pesos/kg, with no variation compared to september 2006 price in the same market. There is no information available in the National Market System in terms of amount (kg or tons) of product bought-sold in these wholesale markets.

Regulations for production and transport of seafood in Mexico

How bivalves are produced and transported have direct implications on health. Annex 3 summarizes current legislation related to aquaculture in Mexico.

The National Service of Sanitary, Safety and Food Quality SENASICA has published a Manual of Good Practices for Bivalve Molluscs aquaculture production for Food Safety (Calvario and Montoya, 2003). This manual provides important guidance on how to develop safe, healthy bivalves aquaculture production and transportation, to fulfil with Mexican law. This manual is used by SENASICA for training and extension courses to farmers and processors in the country.



Figures 8 a (above) and 8 b (below). 2000-2005 price behavior of oysters (shell-on) in wholesale markets of La Nueva Vega (a) and Zapopan (b). Source: Sistema Nacional de Información e Integración de mercados

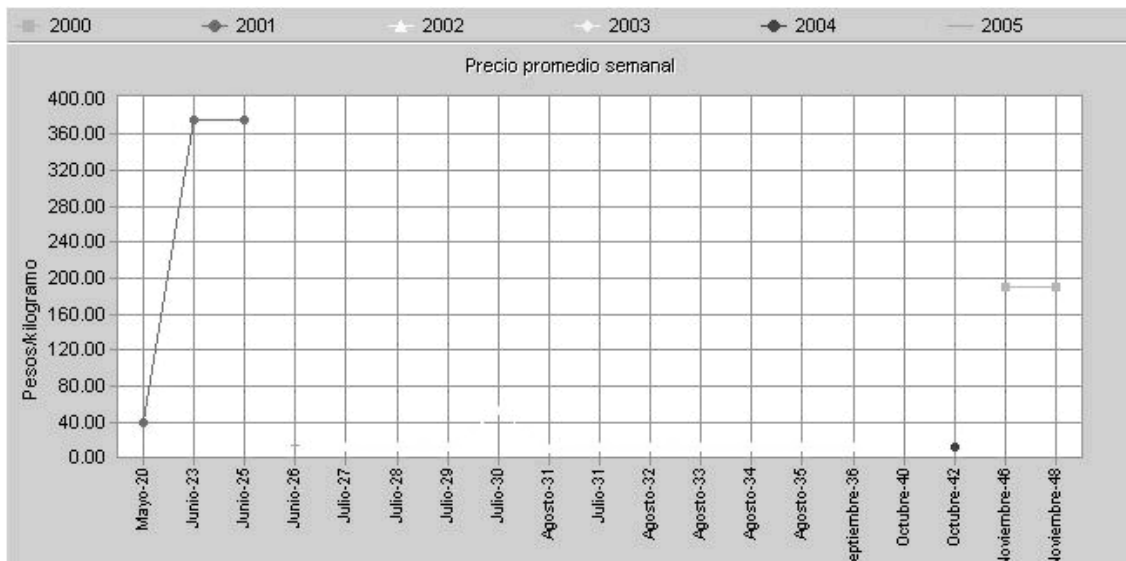
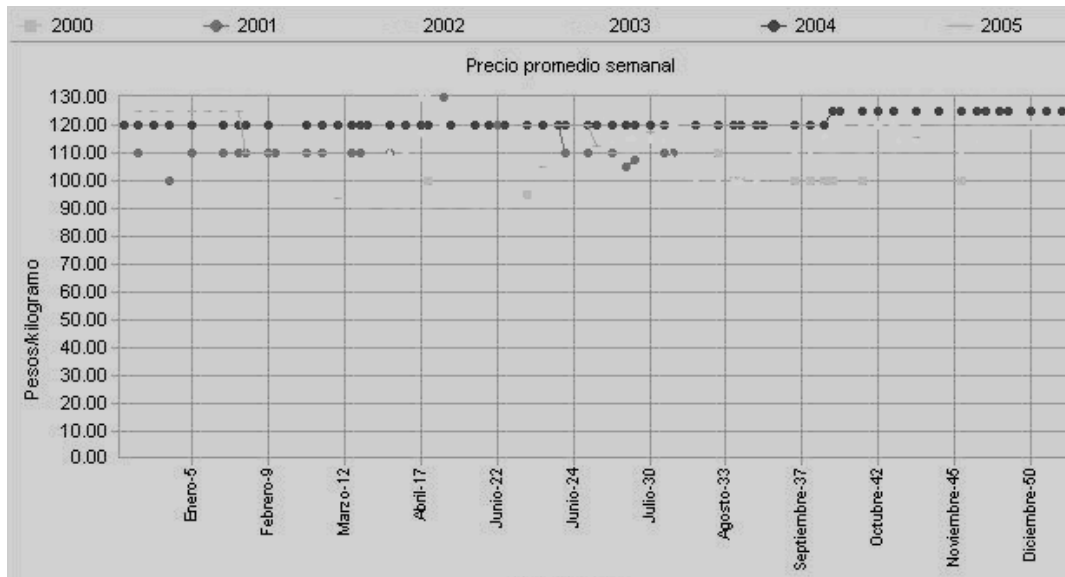


Figure 9a (above) and 9b (below). 2000-2005 price behaviour of oyster (shell-off) in wholesale markets of La Nueva Vega (a) and Zapopan (b). Source: Sistema Nacional de Información e Integración de mercados.

Marketing strategy

All previous results of this market survey are directed towards identification of a successful marketing strategy for the stakeholders: the social cooperatives producing oysters by aquaculture in Bahía Santa María.

When the market analysis is finalized, the marketing strategy is derived and constitutes the foundation of a marketing plan. The marketing plan contains a set of specific actions required to successfully implement the marketing strategy. In a way, the strategy defines tactics to achieve the marketing goal. Marketing strategies serve as the fundamental underpinning of marketing plans designed to fill market needs and reach marketing objectives. They can include advertising, channel marketing, internet marketing, promotion and public relations, all them coordinated. Marketing strategies are dynamic and interactive.

In this study, in order to define a marketing strategy for the Bahia Santa Maria stakeholders, the Porter (1980) generic marketing strategy is used. Porter (1980) proposed that there are three generic marketing strategies that a business can use: segmentation strategy, differentiation strategy, and cost leadership. These three generic strategies are defined along two dimensions: strategic scope and strategic strength (Figure 10). Strategic scope looks at the size and composition of the market, whereas strategic strength takes into account the strength or core competency of the firm. Of these competencies, Porter gives relevance to product differentiation and product cost (efficiency).

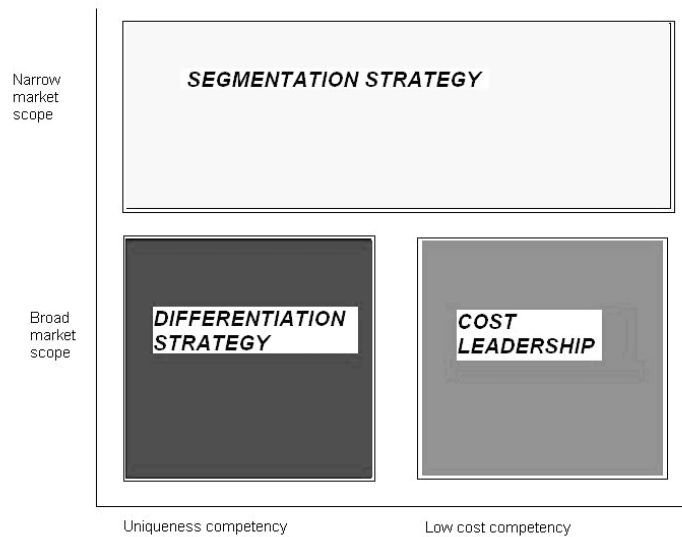


Figure 10. Porter’s Generic Strategies (from Porter, 1980).

Our stakeholders will be small-scale producers of oysters, offering to the market a product (Japanese oyster) which is not a luxury good, and the final customer is used to eating it in the region thanks to cultural heritage. For this kind of small enterprises, the correct marketing strategy seems to be **segmentation strategy**, where the firm concentrates on a select few target markets. This strategy is also called a focus strategy or niche strategy.

In this case, it is considered that the stakeholders would preferably focus on the regional, small markets which were surveyed. This market is well developed, but is also growing according to survey responses from restaurant and trays owners. By focusing their marketing efforts on this narrow market segments but also tailoring the marketing mix to big size oyster, with a continuous

annual supply, it is considered that the stakeholders would better meet the needs of the market. In this strategy, the firms are looking to gain a competitive advantage through effectiveness rather than efficiency. Porter states another characteristic of this strategy, that fits to the market and suppliers analyzed: this strategy is used to select targets that are less vulnerable to substitutes or where a competition is weakest to earn above-average return to investments.

It is important to underline the revealed preferences of restaurants and kiosk owners for a product that is safe, consistent good quality, with year-round availability. This certainly defines a market window and an opportunity for BSM oyster producers to penetrate the surveyed market. As discussed previously, potential buyers are willing to pay an extra \$0.5-1.00 peso per piece, assuming the product fulfills with their demands in terms of quality and quantity. Moreover, given the lack of price sensitivity for fresh, shell-on oysters in the local markets at this time, stakeholders may consider entering the market around BSM as soon as possible to take advantage of higher prices and develop strong relationships with their potential customers.

In response to the desire for safe oysters, producers of oysters may also consider giving correct relevance to the preferences for healthy, safe and good quality product. Although not in place yet, a process of safety guarantees may need to be enforced in the near future for the oyster market. In this sense, proper site selection, adoption of Good Management Practices for production and transportation, together with traceability and health certification regime will be critical to distinguish similar products among customers.

At the current level of production, the stakeholders cannot afford to depend on intermediaries to reach the final oyster buyer (restaurants and kiosk owners). When interviewed, the stakeholders already know they will sell directly to end consumers, one of the cooperatives was even thinking of internet advertising. Selling directly to end consumers is not an atypical marketing practice in Mexico. Small-scale farmers usually have higher production costs due to economies of scale. Although oyster production costs for these cooperatives is relatively cheap (for example, labor is often provided by cooperative members for free), direct sales to consumers allow them to increase their profit margin.

The disadvantages of this commercialization strategy are: a) the stakeholders will have to take care of transportation and cold-storage costs. A marketing plan for direct sales requiring transportation should indicate the dates and times of sales. For example, this study shows that restaurant and tray owners would prefer a 3-day supply of oysters on average, but would need a more continuous supply during the hot season, since the shelf-life of the product is reduced and faster substitution of inventories is needed. During the hot season, not only is there a shortage of supply, but also the final consumer is reluctant to eat fresh oysters, knowing that the probability of getting a gastrointestinal illness is greater.

Commercial deals at this small scale levels are mostly by personal communication rather than by formal commercial contracts. Therefore it is in the stakeholder's interest to develop trust and a personal relationship with their potential market.

At this time, it seems that the oyster aquacultural projects in southern Sonora are the main competitors for the potential production. However, when asked about their customers' product preferences in terms of product origin, a majority of the respondents indicated that purchasing locally produced oysters was important to their customers.

As a strategy to differentiate their product, the stakeholders might also consider strategies to educate final consumers about the water quality of the site where the bivalve was reared. Water quality legislation to certify coastal areas where bivalves are reared is still in process of being approved in Mexico. There are several oyster and clam farms which have been approved by the U.S. FDA to export bivalves to the U.S. and a related CRSP-sponsored effort is examining how local shellfish growing grounds can be approved by the Mexican and/or U.S. governments. This

could represent a significant opportunity to improve the competitiveness for local shellfish producers.

To develop a brand to differentiate the stakeholders oysters from others is believed to be a little out of reach at this stage. The market would pay the extra 1.00 peso for a better product, but it doesn't appear to matter if it has a special seal or brand. Thus the market at this small scale is really based on personal communication, trust and confidence in the vendor. Perhaps these should be the immediate goals to achieve for the stakeholders.

Finally, the wholesale markets of La Viga and Zapopa requires a fairly large amount of product on a constant supply basis. Given that the production levels of the producers around BSM are below the minimum required to enter the wholesale market, stakeholders may consider putting their marketing efforts elsewhere until economies of scale is achieved.

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ANNEX 1 MARKET QUESTIONNAIRE

Encuesta de mercado de ostión
Dr. Quentin Fong, Dr. Francisco J Martínez Cordero

- ¿Dónde está ubicado su negocio? _____
- ¿A qué mercado atiende su negocio? _____
- ¿Por cuántos años ha estado en este negocio, y cuánto tiempo ha vendido ostión?

- ¿Quién le surte sus ostiones? Productor primario Distribuidor Otro
- En su opinión, de una calificación a los atributos del ostión que más le interesan de acuerdo a su uso y venta en su negocio. En la escala del 1 al 10, califique los siguientes, siendo 10 el más importante, 5 neutral y 1 el menos importante

___ Oferta constante (en tiempo)	___ Tamaño del ostión
___ Precio	___ Presentación (fresco, sin concha, etc)
___ Método de producción	___ Lugar de origen
___ Sanidad en la producción	___ Sanidad en su traslado y transformación
___ Vida de anaquel	___ Confianza en el vendedor

- De la misma manera como lo hizo en el cuadro anterior, califique por favor los siguientes atributos del ostión que ud busca, siendo 10 el atributo más buscado y 1 el menos deseado. Por favor califique CADA atributo, y puede asignar dos calificaciones similares a dos atributos.

1. Oferta del ostión	2. Tamaño del ostión
___ Estacional	___ Pequeño (talla??)
___ Todo el año, oferta constante	___ Mediano (talla??)
___ Todo el año, oferta intermitente	___ Grande (talla??)

2

Encuesta de mercado de ostión
Dr. Quentin Fong, Dr. Francisco J Martínez Cordero

- Indique por favor cuáles de las siguientes características son importantes para Ud. en la calidad del ostión. 1= no relevante, 10= muy importante

Vida de anaquel	1 2 3 4 5 6 7 8 9 10
Calidad del agua donde crece el ostión	1 2 3 4 5 6 7 8 9 10
Talla uniforme	1 2 3 4 5 6 7 8 9 10
Tamaño del ostión	1 2 3 4 5 6 7 8 9 10
Forma del ostión	1 2 3 4 5 6 7 8 9 10
Cantidad de carne	1 2 3 4 5 6 7 8 9 10
Origen geográfico	1 2 3 4 5 6 7 8 9 10
Consistencia en la oferta	1 2 3 4 5 6 7 8 9 10
Precio	1 2 3 4 5 6 7 8 9 10
Consistencia	1 2 3 4 5 6 7 8 9 10
Método de transporte	1 2 3 4 5 6 7 8 9 10

- Yo prefiero comprar por: docena, peso, centena, costal, otra

- ¿ Prefiero un producto empacado? _____ ¿De qué forma?

- ¿Con qué periodicidad prefiero recibir ostión? _____

- Por favor indique la importancia relativa de los siguientes puntos, en su decisión por comprar ostiones. La escala es del 1 al 10, siendo 1 el menos preferido o menos importante, y 10 el más preferido o importante

- La importancia de disponer del ostión todo el año, en su decisión de compra
1 2 3 4 5 6 7 8 9 10
- La importancia del origen geográfico, en su decisión de compra
1 2 3 4 5 6 7 8 9 10
- La importancia del sabor del ostión en su decisión de compra
1 2 3 4 5 6 7 8 9 10
- La importancia del empacado y presentación del ostión, en su decisión de compra
1 2 3 4 5 6 7 8 9 10
- La importancia de un tamaño mínimo de compra, en su decisión
1 2 3 4 5 6 7 8 9 10

4

Encuesta de mercado de ostión
Dr. Quentin Fong, Dr. Francisco J Martínez Cordero

3. Vida de anaquel ___ 1 día ___ 3 días ___ 10 días	4. Método de producción ___ Cultivo suspendido ___ Cultivo de fondo ___ Cosecha del medio natural
5. Forma del producto ___ En su concha (vivo) ___ Sin concha, fresco ___ Congelado	6. Species ___ Pacific (<i>C. gigas</i>) GIGANTE ___ Atlantic (<i>C. virginica</i>) DE PLACER ___ <i>C. corteziensis</i> DE PLACER
7. Región de origen ___ Norte de Sinaloa (definir región) ___ Sur de Sinaloa (definir región) ___ Otro (definir región y estado)	8. Precio de venta a su negocio _____

- De las regiones indicadas en la pregunta anterior 7, por favor indique en la misma escala utilizada del 1 al 10, las 3 posibles regiones que se indican en la pregunta.

- ¿Por cuánto tiempo ha utilizado al mismo proveedor de ostión? Por favor utilice el siguiente cuadro, indicando proveedores primarios y secundarios y la antigüedad

Principal	Secundario	Terciario	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	menos de 6 meses
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6-12 meses
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	1-3 años
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Más de 3 años

- ¿Hay algún mes en que no consigue el tipo de ostión que busca o usualmente vende en su negocio? En caso positivo, estaría Ud. dispuesto a pagar un precio más alto, pero para tener una oferta de ostión constante en tiempo y calidad?

3

Encuesta de mercado de ostión
Dr. Quentin Fong, Dr. Francisco J Martínez Cordero

- La importancia del tamaño del ostión, en su decisión
1 2 3 4 5 6 7 8 9 10
- La importancia de calidad de agua, en su decisión
1 2 3 4 5 6 7 8 9 10
- La importancia del precio del producto, en su decisión
1 2 3 4 5 6 7 8 9 10
- La importancia de su confianza en el vendedor del ostión, en su decisión
1 2 3 4 5 6 7 8 9 10
- La importancia de que el producto sea único o innovador, en su decisión
1 2 3 4 5 6 7 8 9 10

- Indique su posición en relación a la siguiente afirmación: "El mercado de ostiones en mi ciudad o región está creciendo"

Estoy fuertemente de acuerdo Estoy de acuerdo Neutral En desacuerdo
Fuertemente en desacuerdo

- Indique la opinión de sus clientes en relación a los siguientes puntos:

Mis clientes prefieren comprar ostión producido en la localidad o alrededores	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé
Al cliente le interesa saber el origen del ostión (geográfico)	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé
El precio del ostión es importante para mis clientes	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé
Mis clientes prefieren ostión vivo, en su concha	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé
Conocer la fecha de cultivo del ostión es importante para mis clientes	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé
Mis clientes prefieren ostión procesado o transformado	Fuertemente de acuerdo	No estoy de acuerdo	No Opinión	De acuerdo	Fuertemente de acuerdo	No sé

- ¿Cuánto ostión estima Ud. comprar en un mes? ¿Al año?

5

Encuesta de mercado de ostión
Dr. Quentin Fong, Dr. Francisco J. Martínez Cordozo

18. ¿Estaría Ud. dispuesto a pagar un poco más por un ostión de mejor calidad, mejor tamaño, o mejor disponibilidad en el año? Precio

19. ¿Qué otros productos (pescados y mariscos) vende Ud.?

20. ¿En relación al ostión, cuáles son los productos de mayor venta en su punto de distribución?

21. ¿Cuál considera Ud. que es un producto (bivalvo) que compite con el ostión en el consumo de su clientela? Precio

MUCHAS GRACIAS POR SU TIEMPO Y DISPOSICION PARA COOPERAR CON ESTE ESTUDIO DE MERCADO. LE REITERAMOS QUE SUS RESPUESTAS SERAN CONSERVADAS EN EL ANONIMATO Y SE USARAN SOLAMENTE EN ESTE ESTUDIO.

ANNEX 2

LIST OF LOCAL (UP TO 2.5 HRS BY ROAD) POTENTIAL BUYERS

LA REFORMA ANGOSTURA SIN.

Restaurant Miramar (La Playita)
Propietario.- Jesús Castro Castro
Teléfono.- 697 73 3-09-96

Restaurant Cancuncito (La Playita)
Propietario.- José Maria Castro
Teléfono.- 697 73 3-09-95

Pescadería Raúl (La Playita)
Propietario.- Armando Montoya
Teléfono.- 697 73 3-08-33

Pescadería Raúl (La Playita)
Propietario.- Arnoldo Montoya
Teléfono.- 697 73 3-07-30

Restaurant 3 Marthas (La Playita)
Propietario.- Martha Beatriz Montoya Ceyca
Teléfono.- 697 73 3-04-34

Mariscos Bahía de Santa Maria

Propietario.- Álvaro García Sánchez
Domicilio.- Rió Acaponeta.
Teléfono.- 697 73 3-05-79

CHNITOS, ANGOSTURA, SINALOA

Mariscos Chayon
Propietario.- José del Rosario Gutiérrez
Domicilio.- Lucio Blanco y Blvd. Madero.
Teléfono.- 697 7020767.

Mariscos Jaziel.
Propietario.- José Antonio González.
Domicilio.- Lucio Blanco, salida Norte Chinitos Áng.

Mariscos el Compa
Propietario.- David Barragán Valle.
Domicilio.- Lucio Blanco, salida Norte, Chinitos Áng.
Cel.- 66 71 44 61 68

Mariscos Chilo's
Propietario.- Isidro Gil Rico.
Domicilio.- Lucio Blanco, salida Norte, Chinitos Áng..
Teléfono.- 6977420038

ANGUSTINA RAMIREZ, ANGOSTURA SIN.

Mariscos Gamez
Propietario.- Jaime Gamez
Domicilio.- Agustina Ramírez, Carretera Reforma – Angostura
Cel.- 69772 93671

ANGOSTURA SINALOA

Mariscos el Terry
Propietario.- Everardo Sánchez Castro
Domicilio.- Carretera Angostura – Guamúchil.
Cel.- 6672 21 27 18

Mariscos Molcajete.
Propietario.- Roberto Quesada Olivas.
Domicilio.- Entronque Angostura – La reforma
Cel.- 045 6142 249660

ALHUEY ANGOSTURA

Mariscos el Ancla
Propietario.- Jesús Guadalupe Borquez
Domicilio.- Carretera a guamúchil.
Tel.- 697 72 9 51 48

GUAMUCHIL SALVADOR ALVARADO SIN.

Mariscos la Ventana del Mero.
Propietario.- Fredy García Leyva
Tel.- 673 4-17-63 y 2-70-25.

Mariscos Rosales y Trueba (Mariscos Jorge)
Propietario . Jorge
Tel. 673 73 2-27-62

Mariscos El Rey.
Propietario.- Raymundo Castro Pérez
Teléfono.- 673 10 67346

Mariscos La Cuchilla
Propietario.- Patricia Guadalupe Alameda
Teléfono.- 673 11 44702 y 673 73 2-89-76

Mariscos La Campechana
Propietario.- Cruz Parra Barraza.
Teléfono.- 673 73 4-30-39

Mariscos Sol y Mar
Propietario.- Virgen Parra
Teléfono.- 673 73 2-14-58

Mariscos el Tanque
Propietario.- Roberto Carlos Vargas.
Teléfono.- 673 73 2-20-44

Mariscos el Tanque (suc. El tanque)
Teléfono.- 673 73 4 40 60

Mariscos Los Tanques (suc. Los Tanques)
Teléfono.- 673 73 4-17-17

Mariscos El Terry
Propietario.- Lorena Sánchez.
Domicilio.- Rosales y Carranza
Teléfono.- 673 73 2-44-24

Mariscos los Algodones (Suc. Mezquites)
Propietario.- Daniela Villa.
Teléfono.- 673 10 8-01-28

Mariscos Los Algodones (Suc. Internacional)
Propietario.- Víctor Hugo Villa.
Teléfono.- 673 10 8-01-26 y 2-59-66

Mariscos las Palmas (Internacional)
Propietario.- Angelina Ochoa Molina
Teléfono.- 673 85 2-32-17

Mariscos el Güero (Carretera a Mocosito)
Propietario.- José Ramón Montoya.
Teléfono.- 697 73 2-38-56

COSTA AZUL ANGOSTURA SIN.

Mariscos el malecón
Propietario.- José Miguel Encines Ruelas
Tel.- 69710 2 47 16

Restaurant de Mariscos el paraje del Chito.
 Propietario.- Perfecto Alonso Ruelas Beltrán.
 Tel.- 697 72 9 61 57

Restaurant Perla Negra
 Propietario.- Jesús González Castro
 Teléfono.- 697 10 4 51 04

PLAYA COLORADA ANGOSTURA.

Restaurant Punta de Guadaron
 Propietario.- José Guillermo Arce Pérez
 Teléfono.- 697 73 4-13-46

ANNEX 3

MEXICAN OFFICIAL LAWS, REGULATIONS AND STANDARDS RELATED TO AQUACULTURE

Mexican Official Standard (NOM)	Description and Objective	Date of Publication
059-ECOL-2001	Determine all flora and fauna terrestrial and aquatic species, subspecies that are endangered, treated, facing extinction, rare or under special protection and establishes specific rules for its protection.	Amended March 6, 2002
PROJECT 089-ECOL-1994	Establishes maximum allowed limits for pollutants contained in residual waters discharged from aquaculture activities into receptor water bodies.	September 20, 1994
Federal Law for Fisheries	It is the legal framework for fisheries and aquaculture, oriented towards sector sustainable development.	Amended June 25, 1992
Federal Law Fisheries Regulation	Chapter III. Specifically related to aquaculture	Amended Sept 29, 1999
NOM-009-PESC-1993	Mexican Official Standard (NOM), to establish procedures to determine zones and duration of close fishing season and capture of aquatic species in federal waters of Mexico.	March 4, 1994
NOM-010-PESC-1993	Establish sanitary requirements for the importation of aquatic organisms in any development stage to be used for aquaculture or ornamental culture in the country.	August 16, 1994
NOM-011-PESC-1993	Regulate application of quarantine, to prevent introduction and dissemination of certifiable disease during importation of live aquatic organisms in any stage of development to be used for aquaculture or ornamental culture in the country.	August 16, 1994
NOM-EM-001-PESC-1999	Modification and extend validation of the emergency official standard, to prevent and control the introduction and dissemination of pathogenic agents causing the disease named White Spot Viral Syndrome (WSSV) and Yellow Head Virus (YHD).	Amended February 22, 2000
NOM-EM-003-PESC-2000	Emergency norm to regulate requirements to determine presence of viral disease in live, dead crustaceans and their products or sub-products, in any presentation, and the artemia (<i>Artemia spp</i>) to introduce and move into the country.	Amended April 25, 2000
NOM-EM-001-PESC-1999	Requirements to prevent and control introduction and dissemination of viral diseases named white spot virus (WSBV) and yellow head virus (YHV).	March 17, 1999
EM-05-PESC-2002	Establish requirements and measures to prevent and control dissemination of high impact disease and for the use of antibiotics in shrimp culture in the country.	July 19 2002

Annex 3 (continued)

Mexican Official Standard (NOM)	Description and Objective	Date of Publication
PROJECT 020-PESC-1994	Explain approved techniques for the identification of pathogens causing diseases in live cultured and wild aquatic organisms and the ornamental ones in the country.	December 7, 1994
PROJECT 021-PESC-1994	Regulate artificial feeds, manufacture ingredients, feeding non-conventional products used in aquaculture and ornamental culture, imported and national for their commercialization and consumption in Mexico.	January 20, 1995
PROJECT 022-PESC-1994	Establish regulations for hygiene and control and the application of Hazard Analyses of Control Critical Points (HACCP) procedures in farming and culture infrastructure.	January 26, 1995
Notification	To acknowledge zones and duration for closed fishing season for aquatic fauna species and its complementary to NOM-009-PESC-1993.	March 4, 1994
NOM-030-PESC-2000	Requirements to determine presence of viral diseases in aquatic crustaceans alive, dead, their products and subproducts in any form and <i>Artemia (Artemia spp)</i> , for their introduction to national territory and movement within the country	January 15, 2002
NOM-003-ECOL-1997	Establishes maximum allowed limits of contaminants for treated residual waters that are re-used in services to the people	September 21, 1998
NOM-EM-006-PESC-2004	Emergency norm that establishes the sanitary aquaculture requirements for the production and movement of aquatic crustaceans, alive, dead, their products and subproducts, and for their introduction in national territory	January 20, 2004

Source: Martínez-Cordero (2006)

**DEVELOPMENT OF AN AQUACULTURE HANDBOOK FOR EXTENSION WORKERS AND TRAINERS OF
EXTENSION WORKERS AND SUB-SAHARAN AFRICA**

*Eleventh Work Plan, Applied Technology & Extension Methodologies 11 (11ATER6³)
Final Report*

Published as Submitted by Contributing Authors

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ABSTRACT

Between 2000 and 2003 as series of twelve short courses focusing on pond construction, pond management, and the economics of fish farming were offered to Fisheries Officers (FOs) and Fisheries Assistants (FAs) of the Kenya Fisheries Department as part of the research and training efforts of the Aquaculture Collaborative Research Support Program (ACRSP). The training materials used in these courses were developed by the collaborating principal investigators to meet the specific needs of these two groups of trainees, drawing on past experience in Kenya (CRSP-sponsored research at Sagana Fish Farm and in On-Farm Trials), information from CRSP research sites in other countries, and published aquaculture literature, and recognizing that most of the intended audience (FOs and FAs) had never previously received any kind of training in aquaculture. Insofar as possible, training materials were organized into PowerPoint® “modules” for use in the classroom setting and supplemented with a large amount of practical work in the field.

Following completion of the twelfth training session it was deemed desirable to organize the PowerPoint® module material into a handbook that could be used not only for future short courses but also as a reference manual for workers involved in aquacultural extension activities in Kenya. This report describes the development of the draft of that manual and a companion document, an “Instructor’s Guide” containing supplemental material for instructors in future training sessions.

INTRODUCTION

Aquaculture development planners in Sub-Saharan Africa have repeatedly recognized that fish farmers and extension workers in the region have suffered from a lack of information about good pond management practices and technology alternatives, and that this lack of information has contributed to low production in many areas (Wangila 1996, PD/A CRSP 1997, CTA 2001). Training for personnel who are supposed to be engaged in aquaculture extension activities has therefore been targeted to relieve this constraint to the development of aquaculture (CRSP Planning Workshop 1997, PD/A CRSP 1997, PD/A CRSP 1999, PD/A CRSP 2001).

³ This previously unpublished final technical report from WP11 is associated with the work for the 12ATE11 investigation. It provides details about the production of *A New Guide to Fish Farming in Kenya* (2008) by Charles C. Ngugi, James R. Bowman, and Bethuel O. Omolo.

In its Africa Project, centered in Kenya, the PD/A CRSP has therefore spent considerable effort during its Ninth and Tenth Work Plans working with the Kenya Fisheries Department (FD) and the Moi University Department of Fisheries (MU) to train FD Fisheries Officers and Fisheries Assistants. Between 1998 and 2003 approximately 248 FD personnel have received practical instruction in either two- or three-week short courses in pond construction, pond management, and economic and business aspects of pond and farm operation (PD/A CRSP 2003, PD/A CRSP in press).

Trainers involved in these efforts have felt handicapped by a lack of aquaculture training materials suitable for use in this region, and have therefore felt the need to develop individual subject-matter teaching modules for use in these short courses. This effort began with a specific WP9 PD/A CRSP training module development activity, *Development of Training Modules of Aquaculture Extension Workers and University Students in Kenya* (Ngugi et al. 2002), and additional modules have been developed by various instructors during the course of WP9, WP10, and WP11 training sessions. As the series of short courses conducted under CRSP sponsorship is concluded, and with the return of trainees to their posts around Kenya, it is desirable to compile the teaching materials and modules that have been developed into a handbook to be made available as an extension reference in Provincial and District Offices in Kenya as well as in other Kenyan institutions—e.g., Moi University—who provide extension services to farmers. This compilation will also serve as a manual for use by trainers involved in future short courses, and can be available to workers in other countries in the region.

OBJECTIVE

To provide a draft aquaculture handbook/teaching manual for use by aquaculture extension workers and trainers of extension workers in Kenya. Draft to be submitted to the ACRSP Program Management Office (IMNC) for final editing and production.

MATERIALS AND METHODS

PowerPoint® modules and other instructional materials developed for and used during training sessions previously held for FD Fisheries Officers and Fisheries Assistants (Ngugi et al. 2002, Veverica et al. 2003, Ngugi et al. 2003, Ngugi et al. in press) were used as the basis for this handbook/ training manual. PIs working on this project began discussions on how to approach the effort and agreed on a division of tasks during the final WP11 training session in August 2003. Each PI worked on his assigned sections from then through August 2004. The PIs also held a work session at the Kenya Wildlife Service Training Institute (KWSTI), from 27-30 April, 2004, to discuss progress and work together on the project.

It was agreed at the outset that the handbook would not consist simply of a collection of the already developed PowerPoint® modules themselves, but that these modules would form the basis for individual sections or chapters in the final product, which would be in the form of a printed handbook. As a final product, the PIs now envision a small “Fish Farming Guide” that can easily be carried to the field by farmers or extension workers. Our model for this guide is an earlier guide, entitled *An Elementary Guide to Fish Farming in Kenya*, produced in 1988 by the Kenya Fisheries Department (Fisheries Department, Ministry of Regional Development, 1988). That guide was a 52-page, soft-cover booklet measuring approximately 15 by 21 cm and less than 0.5 cm thick.

RESULTS

The draft “*Fish Farming Handbook*” will be completed and submitted to the CRSP IMNC separately from this report. We envision producing the handbook in a format similar to that of the FD’s 1988 guide, but including more detail and having perhaps 100 to 150 pages. The tentative title and outline for the “*Fish Farming Handbook*” is as follows:

A Fish Farming Handbook for Kenya

1. Pond Construction
 - Aquaculture planning
 - Pond Design
 - Pond Construction
 - Soils Suitable for Pond Construction
2. Water Quality
 - Important Water Quality Parameters
 - Managing Pond Water Quality
3. Species Suitable for Culture
 - Tilapia
 - Catfish
 - Trout
4. Pond Management
 - Carrying Capacities/Systems
 - Stocking and Harvesting
 - Liming and Fertilizing
 - Nutrition and Feeding
 - Hatchery Management
 - Record Keeping
 - Fish Diseases
5. Economics of Aquaculture
 - Enterprise Budgets
 - Cash Flow Analyses
 - Marketing

In addition to the handbook, we have developed supplemental materials in the form of an *"Instructor's Guide"* (*"Instructors Guide for A Fish Farming Handbook for Kenya"*) to be used with the handbook during training sessions. The instructor's guide provides supplemental information that will allow trainers to use the *Fish Farming Handbook* as a textbook for training courses. This guide includes expanded, more in-depth coverage of key topics, some additional topics, teaching and demonstration ideas for instructors, and a full set of "transparency masters" for use in making transparencies for overhead projection. Transparency masters could also be made available on disk for direct printing to transparencies. We envision the *"Instructor's Guide"* as a loose-leaf bound product of either "letter" or "A-4" size. This size will allow the inclusion of full-size transparency masters and the loose-leaf option will allow additions and changes to be made over time.

ANTICIPATED BENEFITS

This activity will make a practical handbook available to farmers and extension workers in the region. The material included in the *Fish Farming Handbook* will serve as a resource for extension workers who have completed short courses as well as help those who have not attended such courses to better understand proper pond construction techniques and aquaculture principles, leading ultimately to improved pond construction and management and increased productivity by fish farmers. The complementary *Instructor's Guide* will help trainers deliver consistent and comprehensive information to extension workers or farmers attending training courses.

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INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED FISH SPECIES IN CAGES
AND LOW-VALUED SPECIES IN OPEN PONDS: CLIMBING PERCH (*ANABAS TESTUDINEUS*) AND CARPS
IN BANGLADESH

Twelfth Work Plan, Applied Technology & Extension Methods 1a (12ATE1a)

Final Report

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ABSTRACT

An on-farm trial was conducted to evaluate the growth performance of caged climbing perch (*Anabas testudineus*) with six carp species (*Hypophthalmichthys molitrix*, *Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus*, *Puntius sarana* and *Cyprinus carpio*) stocked in the open water of 18 rural farmers' ponds for 150 days in Mymensingh region of Bangladesh. One or two 1-m³ cage per 200 m² pond area was suspended in each of 12 earthen ponds, and the remained 6 ponds served as controls without cages. Climbing perch fingerlings of 2-3 g in size were stocked at 200 and 400 fish per m³ in cages, while carp fingerlings of 8-15 g size were stocked at 1 fish per m² in all eighteen ponds, giving caged climbing perch to open-pond carps ratios of 1:1 and 2:1, respectively. Caged climbing perch were fed commercial pelleted feed (32% crude protein; Saudi Bangla Co. Ltd., Bangladesh) for the first 90 days and grower feed (38% crude protein) for the rest days. Feeds were supplied at 10% body weight per day for the first month and at 5% body weight per day for the rest of the culture period. No fertilizers were applied in the treatment ponds with cages, while the control ponds were fertilized every 2 weeks at rates of 2,000 kg cowdung, 25 kg urea and 25 triple super phosphate per hectare. No additional supplemental feeds were supplied for open-pond carps.

Survival of climbing perch was 61.7% in the 1:1 ratio treatment, which was significantly higher than that (30%) in the 2:1 ratio treatment ($P < 0.05$). There was no significant difference in survival of carps between treatments ($P > 0.05$). Final mean weights of climbing perch were not significantly different between the treatments ($P > 0.05$), while final mean weights of carps in the control were significantly lower than those in the two treatments ($P < 0.05$). Total net yield of climbing perch in the 1:1 ratio treatment was 0.13 ± 0.01 t ha⁻¹ crop⁻¹, which was significantly higher than that (0.10 ± 0.01) in the 2:1 ratio treatment ($P < 0.05$). Total net yield of carps was significantly lower in the control than in the two treatments ($P < 0.05$).

FCR was high in both treatments (11.3 and 25.1), and FCR in the 1:1 ratio treatment was significantly lower than in the 2:1 ratio treatment. Overall, FCR was better in the low density treatment. Survival of every carp species was significantly lower in the control than that in the two treatments. Net and gross yields of each carp species were significantly higher in the two

treatments than those in the control. Net revenues were positive but low in all treatments. Large size climbing perch fingerlings stocked at low density may be suitable for integrated cage-pond culture, but more on-farm trials are necessary to develop the technology.

INTRODUCTION

The present rate of increase in fish production in Bangladesh is lower than that of the population. Thus, much effort needs to be employed to increase fish production in all available inland water bodies to fulfill the protein demand of the people. The vast water bodies of Bangladesh have yet not been properly utilized for fish culture due to lack of adequate knowledge and proper technologies. Therefore, culture system development is one of the most important factors to increase fish production. Among the various culture systems, integrated aquaculture is very suitable in the context of Bangladesh. The integrated aquaculture systems may be of various types, including the integrated cage-cum-pond fish culture system, which is a new concept.

Integrated cage-cum-pond culture is a system in which high-valued fish species are fed with artificial diets in cages that are suspended in ponds, where filter-feeding fish species are stocked to utilize natural foods grown on cage wastes. This integrated system has been developed and practiced using combinations of catfish-tilapia (Lin, 1990; Lin and Diana, 1995) and tilapia-tilapia (Yi et al., 1996; Yi, 1997; Yi and Lin, 2000, 2001) at the Asian Institute of Technology (AIT), Thailand and carps-stinging catfish (Wahab et al., 2005) at the Bangladesh Agricultural University (BAU) at Mymensingh. Although cages were set up using Nile tilapia monoculture ponds in previous work, this integrated system may be applied in polyculture systems as well. In polyculture, ponds are stocked with several carp species of different feeding habits. It is impossible to target feeding to only high-valued species in polyculture, because low-valued species consume the expensive feed resulting in economic inefficiency unless an integrated system is adopted. Compared to the nutrient utilization efficiency of about 30% in most intensive culture systems (Beverage and Phillips, 1993; Acosta-Nassar et al., 1994), nutrient utilization efficiency could reach more than 50% in integrated cage-cum-pond system, resulting in the release of much less nutrients to the surrounding environment (Yi, 1997).

Rural pond aquaculture in Bangladesh is mainly semi-intensive carp polyculture of both Indian major and Chinese carps with low production of $2.8 \text{ t ha}^{-1} \text{ yr}^{-1}$ (DOF, 2001). Pond production systems in many countries have been becoming increasingly reliant on external resources (fertilizer and/or feed) to supplement autochthonous food production for fish. Such systems often discourage small-scale poor farmers in Bangladesh because of low return on investment. On the other hand, such poor farmers have limited financial resources to turn their entire pond to culture high-valued species alone using expensive artificial feeds. However, the integrated cage-cum-pond system may provide an opportunity for small-scale farmers to use their limited resources to include a small amount of high-valued species in their ponds to generate more income and improve their livelihood. This would be achieved through improved nutrient utilization efficiency, marketing of high-valued species and saving fertilizer cost, because there is no fertilization required in open ponds in this system. Also this integrated cage-cum-pond system is environmentally-friendly due to less waste nutrients released to the environment. The purpose of this study was to adapt the integrated cage-cum-pond culture system to local conditions; to determine appropriate stocking density of climbing perch (*Anabas testudineus*) in cages; to assess growth and production of fishes in both cages and open ponds; and to assess economic and environmental benefits.

MATERIALS AND METHODS

This experiment was conducted from 1 September 2005 to 31 January 2006 at rural farms in 18 earthen ponds, ranging from 200 to 640 m^2 in surface area, with an average depth of 2 m. The two sites were located in the eastern and western parts of Haluaghat Upazila, Mymensingh district, Bangladesh. One or two 1 m^3 cages were suspended in each of 12 earthen ponds and other 6

ponds served as controls without cages. Climbing perch fingerlings of 2-3 g in size were stocked in cages while fingerlings of silver carp (*Hypophthalmichthys molitrix*), catla (*Catla catla*), rohu (*Labeo rohita*), mirgal (*Cirrhinus cirrhosus*), rajputi (*Puntius sarana*) and common carp (*Cyprinus carpio*) were stocked at 1 fish m⁻² with a species ratio of 5:4:4:4:2:1 in open water of all ponds. Different numbers of cages for fish resulted in caged to open-pond fish ratios of 1:1, 2:1 and 0:1 as the three treatments (one cage treatment, two cage treatment and control) with six replicates each. One or two cages (1 x 1 x 1 m, water volume of 0.85 m³) were suspended at the middle of each of the treatment ponds. Cages were made with iron rods covered by net, and supported by two vertical and one horizontal bamboo poles for each cage. Fingerlings of all carps species and climbing perch were collected from Brahmaputra Hatchery, Mymensingh and stocked on 1 September 2005 in ponds and cages, respectively. All fishes were kept in hapas for conditioning, and initial length and weight of fingerlings were determined prior to stocking.

Caged climbing perch fingerlings were fed commercial pelleted feed (32.38% crude protein; Saudi Bangla, Bangladesh) twice daily at a rate of 10% body weight per day in the first month and 5% in the rest of the culture period. Feed was supplied on a feeding tray (42×26×4 cm), which was hung in each cage. Feed ration was adjusted every two weeks based on sampling weight and observed mortality of climbing perch. No fertilizers were applied in treatment ponds with cages, while the control ponds were fertilized every two weeks at rates of 2,000 kg cowdung, 25 kg urea and 25 triple super phosphate per hectare. No additional supplemental feeds were supplied for open-pond carps in both control and treatment ponds.

Throughout the experimental period, the following water quality parameters were measured monthly in all ponds. Temperature (°C), Secchi disk depth (cm) and dissolved oxygen (DO, mg L⁻¹) were measured in situ between 0900 and 1000 h. Total alkalinity (mg L⁻¹), pH and total ammonia nitrogen (TAN, mg L⁻¹) were determined at the Water Quality and Pond Dynamics Laboratory of the Faculty of Fisheries, Bangladesh Agricultural University. Temperature and DO were measured by a digital DO meter (YSI model 58), and pH by a pH electrode (Jenway, model 3020). Total alkalinity was determined titrimetrically. TAN was determined by HACH Kit (DR/2010, a direct reading spectrometer).

About 10-20% of the stocked fish were sampled every two weeks, using a cast net from the open ponds and a scoop net from cages. Length and weight of each fish was measured to assess growth rate. At the end of the experiment, water was pumped out of the ponds, and all fish were collected, counted and weighed individually to assess the survival rate, growth and production in each pond. Net fish yield was calculated by deducting fish biomass at stocking from total fish biomass at harvest.

Economic analysis was conducted to determine economic return of the integrated cage-cum-pond culture system for each treatment (Shang, 1990). The analysis was based on market prices in Bangladesh for harvested fish and all other items, which was expressed in Bangladesh Tk (US \$1= Tk 68). Market prices of harvested carps at 50 Tk/kg, climbing perch 250 Tk/kg, carp fingerlings 2 Tk/piece, climbing perch fingerlings 3 Tk/piece, and pelleted feed 20 Tk/kg were applied to the analysis.

Data were analyzed statistically by one-way analysis of variance and linear regression (Steele and Torrie, 1980) using SPSS (version 10.0) statistical software (SPSS Inc., Chicago, USA). Differences were considered significant at $\alpha = 0.05$. Means were given with \pm standard error (S.E).

RESULTS

Water quality parameters

The measured DO concentrations at 1000 h ranging from 2.3 to 8.00 mg L⁻¹ were highest in the control, intermediate in the low density treatment, and lowest in the high density treatment ($P < 0.05$), while temperature fluctuated from 19.1°C to 26.7°C without significant difference among treatments ($P > 0.05$; Table 1 and Figure 1). Overall mean values of pH ranged from 6.3 to 8.3, and

were significantly higher in the low density treatment than the control and high density treatments ($P < 0.05$; Table 1). Mean pH values were highest at the beginning of the experiment and lowest in November after which pH increased again (Figure 1). The overall mean values of total alkalinity in the high density treatment were significantly higher than those in the control and low density treatment ($P < 0.05$), between which there were no significant differences ($P > 0.05$; Table 1). Mean values of total alkalinity were quite stable throughout the experimental period (Figure 2). The overall mean values of total ammonia nitrogen were higher in the high density treatment, variable in the control, and lower in the low density treatment ($P < 0.05$; Figure 2).

Performance of fish

Climbing perch in both treatments grew steadily in the first three months, then declined (Figure 3). Survival of climbing perch in cages was low, ranging from 30% to 61.7% (Table 2), with significantly higher survival in the 1:1 ratio treatment ($P < 0.05$; Table 1). Gross yield of climbing perch was not significantly different between the two treatments ($P > 0.05$), but net yield was significantly higher in the 1:1 ratio treatment ($P < 0.05$; Table 2). FCR was extremely poor in both treatments, with the significantly lower values in the 1:1 ratio treatment ($P < 0.05$; Table 2).

Survival of carps ranged from 50% to 91.7%. The survival rate of each carp species in the control was significantly lower than that in the two treatments ($P < 0.05$), between which there was no significant difference ($P > 0.05$; Table 3). All carp species grew steadily in the first three months, then growth declined in the last two months (Figures 4 and 5). Total gross and net yields of silver carp, catla and rajpunti were highest in the 1:1 ratio treatment, intermediate in the 2:1 ratio treatment, and lowest in the control ($P < 0.05$), while the gross and net yields of rohu, mrigal and common carp in the control were significantly lower than those in the two cage treatments ($P < 0.05$), between which there was no significant difference ($P > 0.05$). Total net and gross yields of all carps as well as the combined net and gross yields of caged climbing perch and open-pond carps were lowest in the control, intermediate in the 2:1 ratio treatment, and highest in the 1:1 ratio treatment ($P < 0.05$; Tables 3 and 4). Overall FCR for both climbing perch and carps in the 1:1 ratio treatment was 0.54, which was significantly better than that (1:07) in the 2:1 ratio treatment ($P < 0.05$).

Economic analysis

All three treatments produced positive net returns (Table 5). The total cost was highest in the 2:1 ratio treatment, intermediate in the 1:1 ratio treatment, and lowest in the control. Both gross income and net return were lowest in the 2:1 ratio treatment, intermediate in the control, and highest in the 1:1 ratio treatment ($P < 0.05$; Table 5).

DISCUSSION

All measured water quality parameters except water temperature were in the ranges for good growth of both climbing perch and carps. However, water temperature, ranging from 19°C to 26.7°C, was quite low during most (November-January) of the experimental period (September – January), and was outside the optimal range for tropical fish species such as climbing perch. The low temperature was probably one of main reasons for slow growth of fish especially climbing perch. Dissolved oxygen content in the ponds did not differ between the control and low density treatments, indicating that the addition of 200 climbing perch into the carp polyculture ponds did not degrade the dissolved oxygen content in the pond water. Total alkalinity was significantly higher in the ponds with two cages than the other treatments, as waste loading was higher, and the use of organic inputs may keep alkalinity at higher level (Knud-Hansen et al., 1992; Diana et al., 1994).

Survival of climbing perch in the present experiment (30%-61.7%) was lower than that (97%-99.6%) reported by Yi et al. (2005) for an on-station trial for integrated climbing perch – Nile tilapia culture conducted in Vietnam, and also lower than that of walking catfish cultured in similar systems (Lin, 1990; Lin and Diana, 1995). Mass mortality of caged climbing perch occurred

during the first three weeks after stocking in the present experiment, due mainly to poor quality of fingerlings as well as EUS (Epizootic Ulcerative Syndrome) disease. Growth of climbing perch was also poor in the present experiment, due partly to the poor quality of feed.

Feeding rate was fixed to 10% body weight per day in the first month and 5% during the rest of the experimental period. However, most of the experimental period was winter with low temperature, causing less food intake and a large amount of uneaten feed. Therefore, mass mortality and low water temperature were the main reasons for very poor FCR in both cage treatments.

In integrated cage-pond aquaculture systems, waste derived from cages can effectively support growth of filter-feeding species such as Nile tilapia in open ponds, and the growth of open-pond fish increases with increasing waste nutrient loading from cages (Lin, 1990; Lin and Diana, 1995; Yi et al., 1996; Yi, 1997; Yi and Lin, 2000, 2001). The results of the present experiment that the growth of carps in the two cage treatments was significantly higher than that in the control without cages are consistent with these studies. However, the large amount of uneaten feed released from cages was most likely another important reason that carp growth in the cage treatments was better than in the control.

Climbing perch is an exotic, newly introduced and high-valued fish species in Bangladesh. Therefore, very few research and breeding programs have been undertaken to improve growth and production performance of this species. The climbing perch has potential to be cultured in a cage-pond aquaculture system, but further improvement of the technology is needed.

ANTICIPATED BENEFITS

Most of the farmers were from a tribal community and they were very interested in integrated cage-cum-pond culture. Therefore, this technology needs to be further improved and adopted to local conditions in Bangladesh. Cage-cum-pond systems might open up a new horizon of pond fish culture for both poor and rich fish growers in Bangladesh as well as other countries in South Asia. It could provide small-scale rural farmers an opportunity to generate increased income and improve their livelihood using their scare resources.

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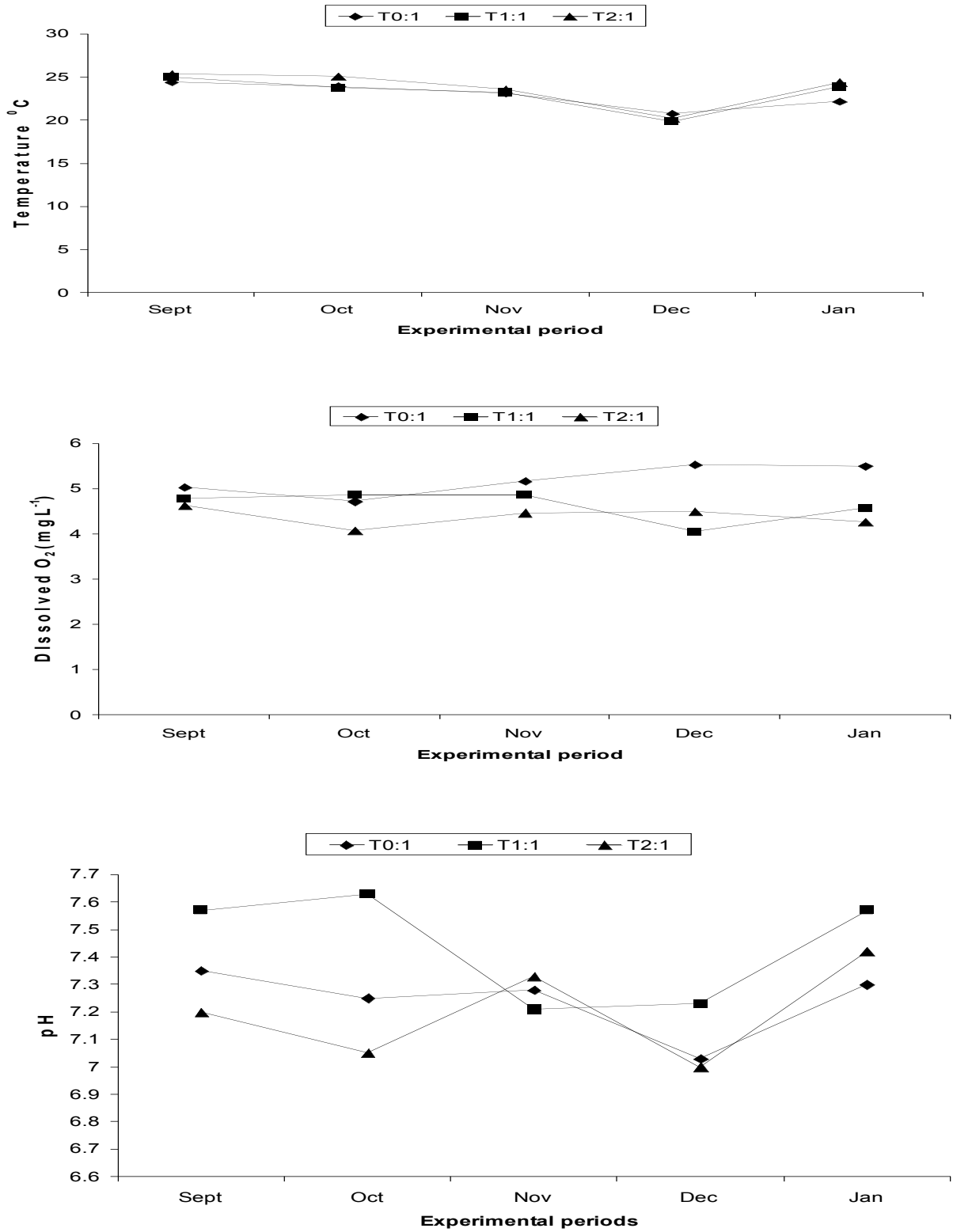


Figure 1. Changes of temperature, DO and pH measured at 1000 h in different treatments throughout the experimental period.

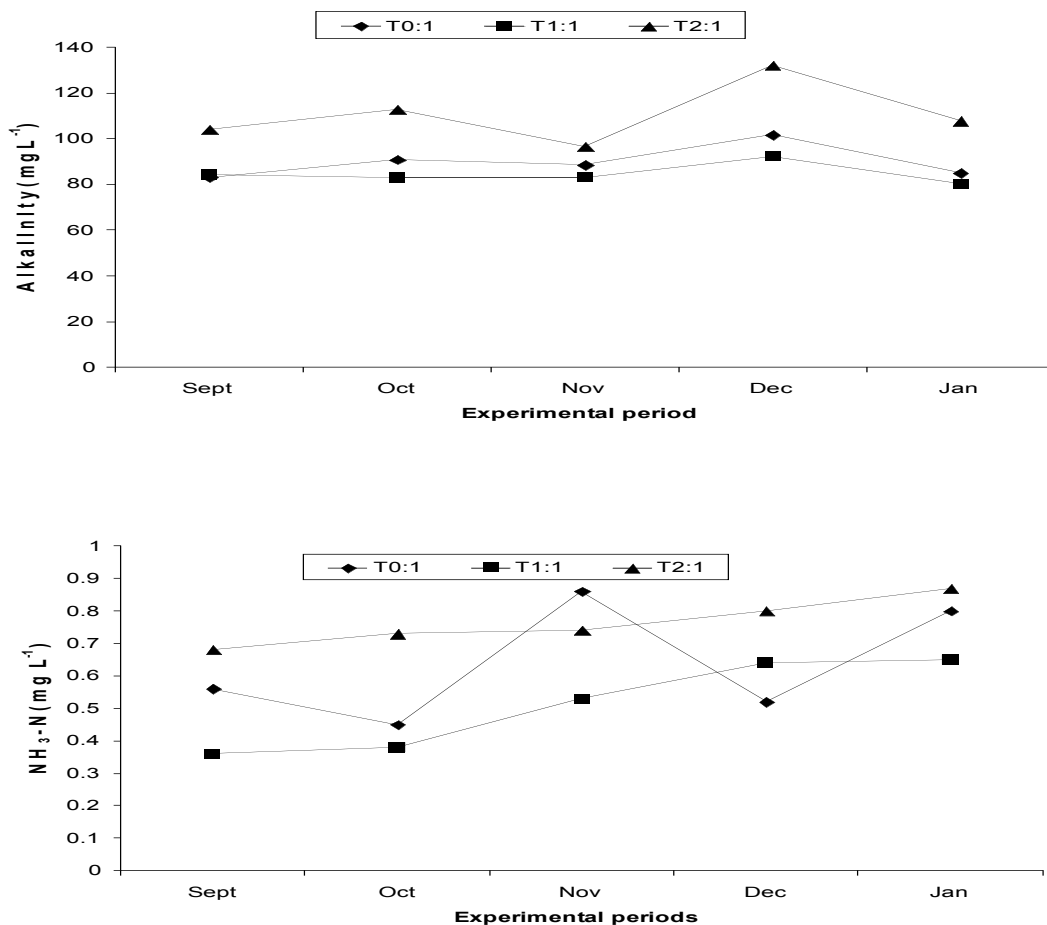


Figure 2. Changes of total alkalinity and total ammonia nitrogen measured at 1000 h in different treatments throughout the experimental period.

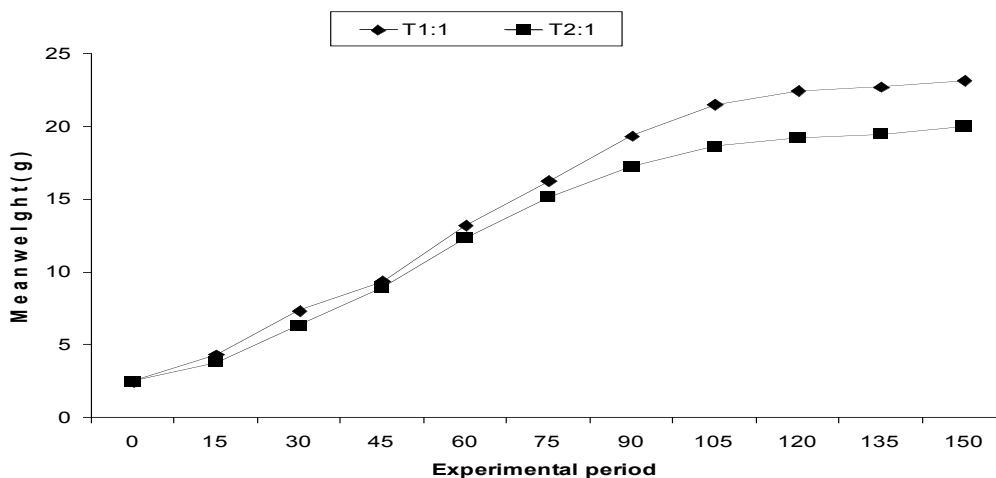


Figure 3. Growth of caged climbing perch in the one- and two-cage treatments.

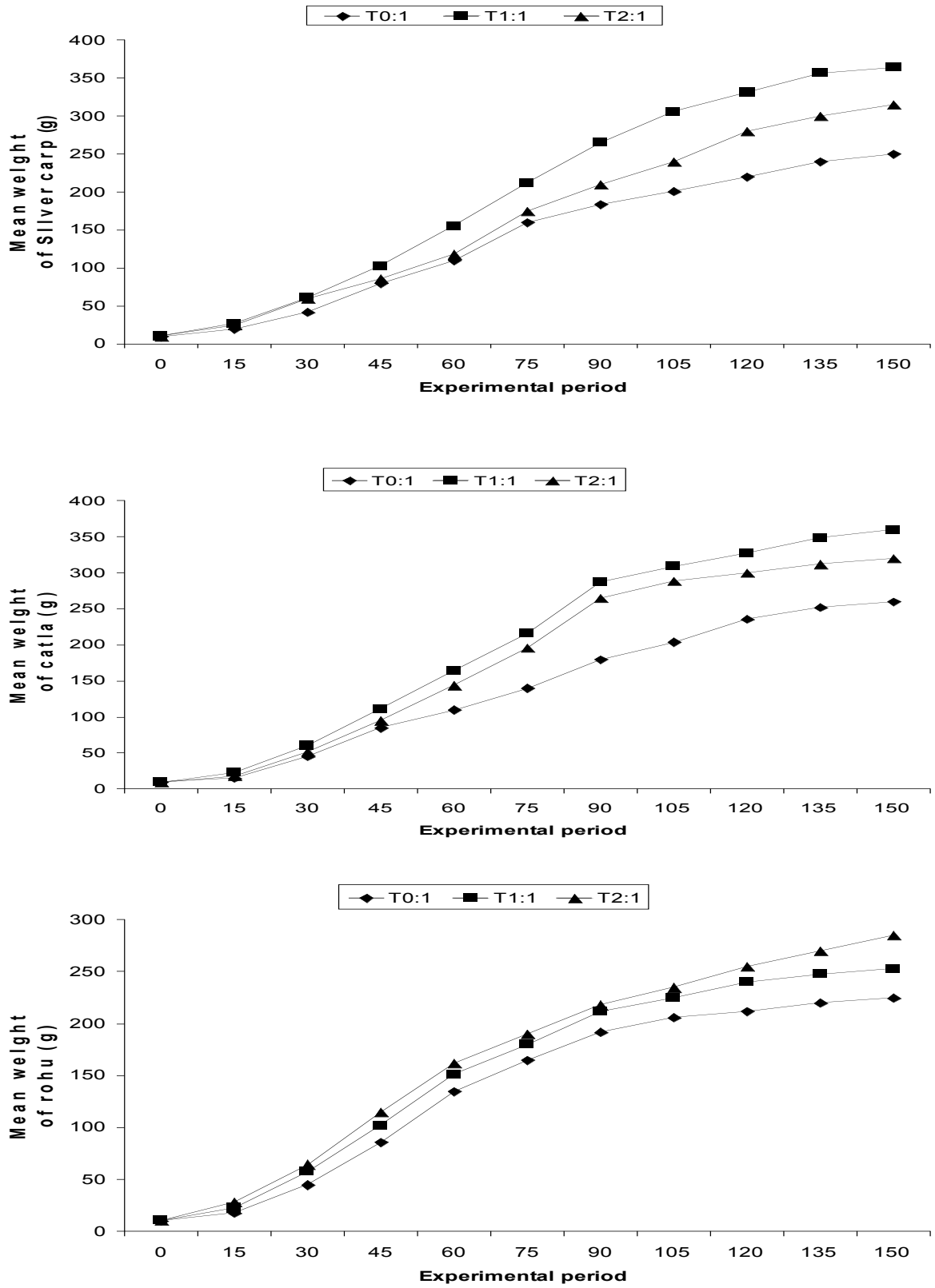


Figure 4. Growth of silver carp, catla and rohu (*Labeo rohita*) in in each treatment.

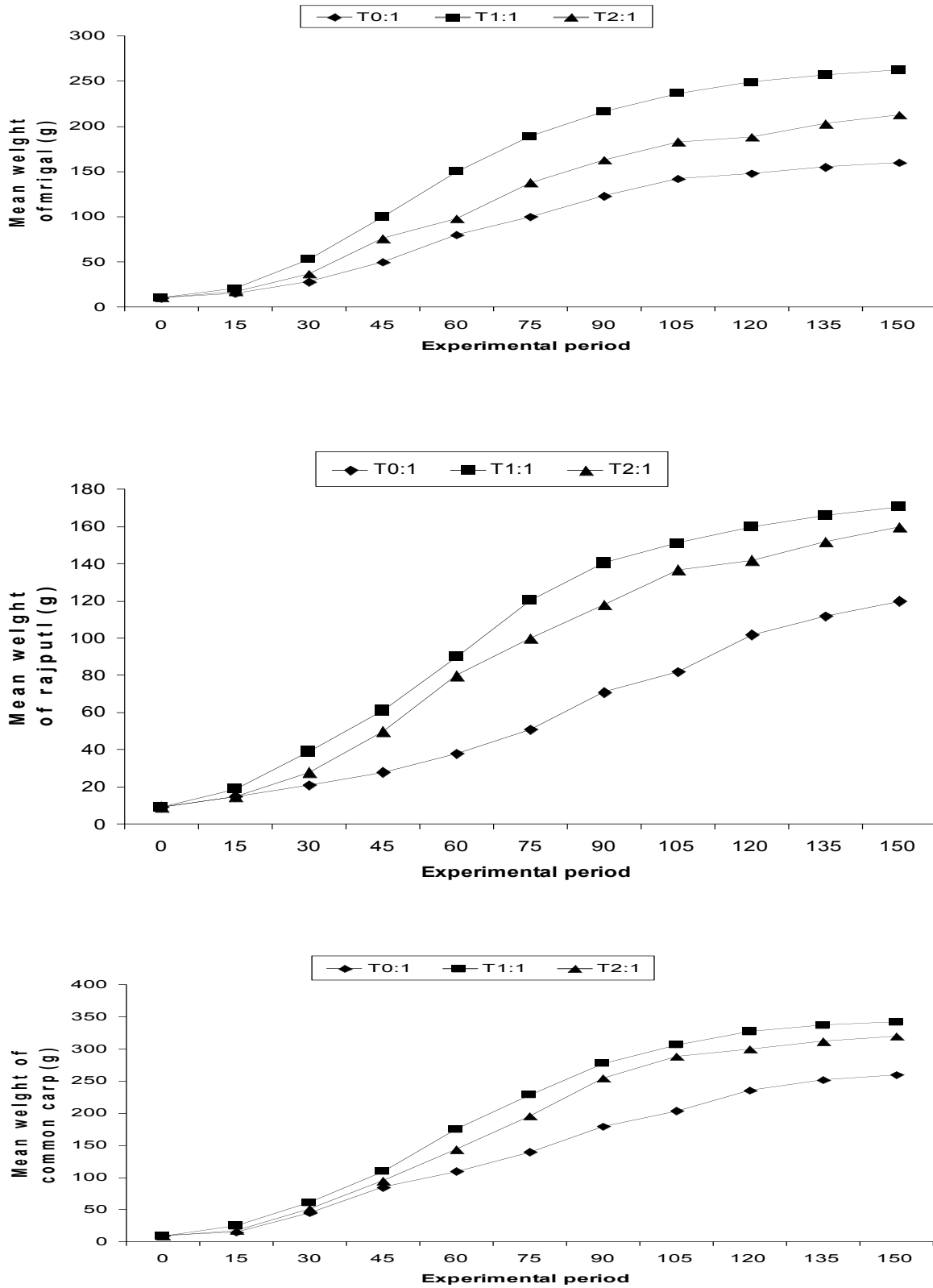


Figure 5. Growth of mirgal, rajputi and common carp in open ponds for different treatments.

Table 1. Overall mean values and ranges (in parentheses) of the measured water quality parameters in all treatments.

Parameters	Ratio of caged fish to open pond carps		
	0:1 (control)	1:1 (one cage)	2:1 (two cages)
DO (mg L ⁻¹)	5.2±1.3 ^b (3.0 – 8.0)	4.6±0.9 ^{ab} (2.5 – 7.0)	4.4±1.2 ^a (2.3 – 7.1)
Temperature (°C)	22.9±1.8 (19.7 – 26.0)	23.1±1.9 (19.2 – 26.1)	23.7±2.1 (19.1 – 26.7)
pH	7.2 ^a (6.8 – 8.0)	7.4 ^b (6.9 – 8.0)	7.2 ^a (6.3 – 8.3)
Total alkalinity (mg L ⁻¹ as CaCO ₃)	93±14 ^a (65 – 130)	85±19 ^a (59 – 150)	111±43 ^b (67 – 220)
TAN (mg L ⁻¹)	0.64±0.43 ^{ab} (0.01 – 1.60)	0.51±0.33 ^a (0.05 – 1.49)	0.76±0.56 ^b (0.07 – 2.94)

* Mean values with different superscripts in the same row were significantly different ($p < 0.05$).

Table 2. Performance of caged climbing perch in different treatments.

Performance	Ratio of caged fish to open pond carps	
	1:1 (one cage)	2:1 (two cages)
Total initial weight (kg cage ⁻¹)	0.50±0.00 ^a	1.0±0.00 ^b
Total final weight (kg cage ⁻¹)	3.04±1.28	3.07±2.24
Total weight gain (kg cage ⁻¹)	2.55±0.12 ^a	2.07±0.17 ^b
Total net yield (t ha ⁻¹ crop ⁻¹)	0.13±0.01 ^a	0.10±0.01 ^b
Survival (%)	61.67±1.86 ^a	30.0±4.73 ^b
FCR	11.31±0.44 ^a	25.13±3.43 ^b

* Mean values with different superscripts in the same row were significantly different ($P < 0.05$)

Table 3. Performance of open-pond carps in all treatments.

Performance	Ratio of caged fish to open pond carps		
	0:1	1:1	2:1
Silver carp			
Total initial weight (kg 200 m ⁻²)	0.53±0.03	0.54±0.04	0.55±0.05
Total final weight (kg 200 m ⁻²)	7.08±0.77 ^a	15.92±1.09 ^c	12.18±1.09 ^b
Total weight gain (kg 200 m ⁻²)	6.78±0.77 ^a	15.44±1.07 ^c	11.72±1.07 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.34±0.04 ^a	0.77±0.05 ^c	0.59±0.05 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.36±0.04 ^a	0.80±0.05 ^c	0.61±0.05 ^b
Survival (%)	57.0±3.74 ^a	87.33±3.50 ^b	85.0±3.74 ^b
Catla			
Total initial weight (kg 200 m ⁻²)	0.42±0.02	0.39±0.02	0.40±0.04
Total final weight (kg 200 m ⁻²)	5.04±1.54 ^a	11.80±1.24 ^c	11.32±1.26 ^b
Total weight gain (kg 200 m ⁻²)	4.77±1.53 ^a	11.46±1.24 ^c	10.95±1.23 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.24±0.07 ^a	0.57±0.06 ^c	0.55±0.06 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.25±0.08 ^a	0.59±0.06 ^c	0.57±0.06 ^b
Survival (%)	62.92±4.85 ^a	88.33±4.38 ^b	91.67±2.58 ^b
Rohu			
Total initial weight (kg 200 m ⁻²)	0.43±0.02	0.43±0.03	0.43±0.03
Total final weight (kg 200 m ⁻²)	3.83±0.35 ^a	8.98±0.25 ^b	10.28±3.53 ^b
Total weight gain (kg 200 m ⁻²)	3.57±0.35 ^a	8.61±0.26 ^b	9.84±3.60 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.18±0.02 ^a	0.43±0.01 ^b	0.44±0.17 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.19±0.02 ^a	0.45±0.01 ^b	0.45±0.08 ^b
Survival (%)	60.0±6.12 ^a	88.75±2.09 ^b	89.17±3.76 ^b
Mrigal			
Total initial weight (kg 200 m ⁻²)	0.42±0.02	0.43±0.03	0.43±0.02
Total final weight (kg 200 m ⁻²)	4.17±0.53 ^a	9.65±1.04 ^b	8.98±1.36 ^b
Total weight gain (kg 200 m ⁻²)	3.92±0.52 ^a	9.25±1.06 ^b	8.59±1.35 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.23±0.10 ^a	0.47±0.05 ^b	0.43±0.07 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.21±0.03 ^a	0.49±0.05 ^b	0.45±0.07 ^b
Survival (%)	59.17±4.65 ^a	91.17±3.03 ^b	90.83±2.58 ^b
Common carp			
Total initial weight (kg 200 m ⁻²)	0.10±0.01	0.09±0.01	0.10±0.02
Total final weight (kg 200 m ⁻²)	1.19±0.15 ^a	3.07±0.41 ^b	3.22±0.40 ^b
Total weight gain (kg 200 m ⁻²)	1.13±0.14 ^a	2.99±0.40 ^b	3.14±0.39 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.06±0.01 ^a	0.15±0.02 ^b	0.16±0.02 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.07±0.01 ^a	0.16±0.02 ^b	0.16±0.02 ^b
Survival (%)	61.67±7.53 ^a	90.0±6.32 ^b	86.67±5.16 ^b
Raj punti			
Total initial weight (kg 200 m ⁻²)	0.18±0.01	0.19±0.01	0.18±0.02
Total final weight (kg 200 m ⁻²)	0.94±0.14 ^a	2.99±0.35 ^c	2.47±0.34 ^b
Total weight gain (kg 200 m ⁻²)	0.85±0.13 ^a	2.83±0.63 ^c	2.32±0.34 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	0.04±0.01 ^a	0.14±0.02 ^c	0.12±0.02 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	0.05±0.01 ^a	0.15±0.02 ^c	0.12±0.02 ^b
Survival (%)	50.00±6.32 ^a	87.50±2.74 ^b	84.17±3.76 ^b

Table 3 (continued)

Performance	Ratio of caged fish to open pond carps		
	0:1	1:1	2:1
All carps			
Total initial weight (kg 200 m ⁻²)	2.08±0.03	2.07±0.02	2.09±0.02
Total final weight (kg 200 m ⁻²)	22.25±1.14 ^a	52.41±1.54 ^c	48.45±1.26 ^b
Total weight gain (kg 200 m ⁻²)	21.02±1.13 ^a	50.58±1.54 ^c	46.56±1.26 ^b
Total net yield (t ha ⁻¹ crop ⁻¹)	1.09±0.08 ^a	2.53±0.12 ^c	2.29±0.17 ^b
Total gross yield (t ha ⁻¹ crop ⁻¹)	1.13±0.07 ^a	2.64±0.10 ^c	2.36±0.14 ^b
Survival (%)	58.5±6.32 ^a	88.85±2.74 ^b	87.9±3.76 ^b

* Mean values with different superscripts in the same row were significantly different ($P<0.05$).

Table 4. Combined performance of caged climbing perch and open-pond carps in all treatments.

Performance	Ratio of caged fish to open pond carps		
	0:1 (control)	1:1 (one cage)	2:1 (two cages)
Total initial weight (kg 200 m ⁻²)	2.08±0.03 ^a	2.57±0.07 ^b	3.08±0.07 ^c
Total final weight (kg 200 m ⁻²)	22.25±1.14 ^a	55.45±0.95 ^c	51.52±4.74 ^b
Total weight gain (kg 200 m ⁻²)	21.02±1.13 ^a	52.88±0.98 ^c	48.44±4.70 ^b
Net yield (t ha ⁻¹ crop ⁻¹)	1.09±0.08 ^a	2.64±0.05 ^c	2.42±0.23 ^b
Gross yield (t ha ⁻¹ crop ⁻¹)	1.13±0.07 ^a	2.77±0.05 ^c	2.58±0.23 ^b
Overall FCR	----	0.54±0.03 ^a	1.07±0.14 ^b

* Mean values with different superscripts in the same row were significantly different ($P<0.05$).

Table 5. An economic analysis for all treatments based on 200 m² pond area in Bangladesh Tk).

Parameter	Ratio of caged fish to open pond carps		
	0:1 (control)	1:1 (one cage)	2:1 (two cages)
Gross income			
Carps	1,112±128 ^a	2,620±39 ^c	2,422±219 ^b
Climbing perch	-	761±28 ^a	768±48 ^b
Total	1,112±128 ^a	3,381±62 ^c	3,190±210 ^b
Operational cost			
Carps fingerlings	400±0	400±0	400±0
Climbing perch fingerling	-	600±0 ^a	1200±0 ^b
Depreciation of cage	-	300±0	300±0
Pelleted feed	-	576±34 ^a	1,033±74 ^b
Total	400±0 ^a	1,876±34 ^b	2,933±74 ^c
Net income	712±128 ^a	1,505±44 ^c	257±253 ^b

*Mean values with different superscripts in the same row were significantly different ($P<0.05$).

INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED FISH SPECIES IN CAGES AND LOW-VALUED SPECIES IN OPEN PONDS: AFRICAN CATFISH (*CLARIAS GARIEPINUS*) AND CARPS IN NEPAL

Twelfth Work Plan, Applied Technology & Extension Methods 1b (12ATE1b)

Final Report

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ABSTRACT

An on-farm trial was conducted for 164 days in 18 earthen ponds of 85-130 m² in surface area at three sites in Nepal to adopt integrated cage-cum-pond systems to local conditions and to verify the best results of an on-station trial. One cage (1.5 x 1.5 x 1.0 m) with water volume of 2 m³ was suspended in ponds. There were two treatments: (1) carps at 1 fish m⁻² in open ponds without cages (control); (2) African catfish (*Clarias gariepinus*) at 100 fish m⁻³ in cages and carps at 1 fish m⁻² in open ponds (cage treatment). Each trial site had 3 replicates for both the control and treatment. African catfish fingerlings of 12.8 – 13.2 g in size were stocked in cages, while fingerlings of silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) of average weights of 4.6, 2.2, 4.2, 0.5 and 0.7 g, respectively, were stocked in the open water of all ponds, giving a stocking ratio of silver carp, bighead carp, common carp, rohu and mrigal as 4:2:2:1:1 in each pond. Caged catfish were fed twice daily with a locally made pellet feed (28% crude protein), while no feed or fertilizer was added into open water. In the control, ponds were fertilized weekly with diammonium phosphate (DAP) and urea at rates of 2 kg N and 1 kg P ha⁻¹ d⁻¹.

Mean total weight, harvest size, growth, gross and net fish yield, survival, and feed conversion ratio of African catfish were 23.1±2.1 kg cage⁻¹, 212.7±12.4 g fish⁻¹, 1.3±0.1 g f⁻¹d⁻¹, 23.1±2.1 kg cage⁻¹ crop⁻¹, 20.6±2.1 kg cage⁻¹ crop⁻¹, 54.9±1.0 % and 2.8±0.2, respectively. Most of the growth and production parameters of silver and bighead carps were significantly higher in the control than in the cage treatment (P>0.05). The net and gross yields of carps in the control were significantly higher than in the cage treatment (P<0.05) while the combined net and gross yields of catfish and carps were significantly higher in cage treatment than in the control (P<0.05). Both the control and cage treatment produced positive net returns with 1,252 NRs per 100-m² pond in the control, and 1,859 NRs per 100-m² pond in the cage treatment in one culture cycle. The results of this trial showed that African catfish has potential to be cultured in the integrated cage-cum-pond culture system, but it is necessary to avoid the winter season for culture. Also, growth and survival of African can be improved by stocking larger size fingerlings and by providing better quality feed.

INTRODUCTION

African catfish (*Clarias gariepinus*) are generally cultured in high stocking density with intensive feeding while carps are cultured in semi-intensive systems with fertilization, with or without supplementary feeding. Since African catfish consume a small fraction of the applied nutrients,

most nutrients are retained in the water which deteriorates water quality (Sundar, 1989). A cage-cum-pond integrated system of African catfish and carps could be ideal to minimize the nutrient load to the water and improve water quality by recycling nutrients to increase other fish production (Uddomkarn, 1989; Lin and Diana, 1995; Yi et al., 2003).

Earlier experiments of cage-cum-pond integration systems were limited to cages in Nile tilapia monoculture ponds (Uddomkarn, 1989; Lin, 1990; Ye, 1991; Lin and Diana, 1995; Yi et al., 2004) though this system can also be applied in polyculture systems with carps. An on-station experiment was conducted in subtropical Nepal during September 2004 to February 2005 to adapt this integrated cage-cum-pond system with African catfish (*Clarias gariepinus*) in cages and carps in open ponds. Based on the results of this on-station experiment, a verification trial was conducted on farms in three different locations.

The purposes of this study were to adopt the integrated cage-cum-pond systems in local conditions in Nepal and to verify on farms the best results of the previously conducted on-station experiment.

MATERIALS AND METHODS

This experiment was conducted for 164 days from 24 July 2005 to 28 January 2006 in 18 earthen ponds of 85-130 m² in surface area and 1.0 m in depth. Three different trial sites were used in Nepal—Kawasoti, Nawalparasi (site-1), Kushana, Kathar, Chitwan (site-2), and Gothauli, Kathar, Chitwan (site-3)—to assess the production and economic performance of an integrated cage-cum-pond with African catfish in cages and carps in ponds. The best treatment from the on-station trial was evaluated in farmers' ponds. There were two treatments: (1) carps at 1 fish m⁻² in open ponds without cages (control); (2) African catfish at 100 fish m⁻³ in cages and carps at 1 fish m⁻² in open ponds (cage treatment). Each trial site had 3 replications of the control and cage treatment. One cage of dimension of 1.5 m x 1.5 m x 1 m covered with 1-cm mesh net was suspended in each of three treatment ponds at each site, and three ponds at each site also served as controls without cages. Water depth was maintained 1.1±0.1m in each pond by topping with canal water to replace water loss due to evaporation and seepage, while water depth in cages was 0.9 m, giving water volume of 2 m³ in cages.

African catfish fingerlings of 12.8-13.2 g in size were stocked in cages, while fingerlings of silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) of average weight 4.6 g, 2.2 g, 4.2 g, 0.5 g and 0.7 g, respectively, were stocked in open ponds, giving species ratio of 4:2:2:1:1. Catfish were stocked on 24 July 2005, while carps were stocked on 5 August 2005.

Caged catfish were fed twice daily at 0900-1000 h and 1500-1600 h, with a locally made pelleted feed (28% crude protein). Feed ration was calculated based only on caged catfish biomass estimated by fish sampling every two weeks. Feeding rates of 5% and 3% body weight per day were used for caged catfish smaller and greater than 100 g, respectively. No feed or fertilizers were added into open ponds. Feed rates were adjusted after each biweekly sampling. Control ponds were fertilized with diammonium phosphate (DAP) and urea at rates of 2 kg N and 1 kg P ha⁻¹ d⁻¹ throughout the trial period.

Locally made pelleted feed (composition: fish meal, rice bran and mustard oil cake at the rate of 5:3:2, respectively) was analyzed for proximate composition (AOAC, 1980). Water temperature and pH in surface water were measured every two weeks at 1000 – 1200 h by using glass thermometer and pH meter (ATC Pocket Meter), respectively.

Growth of caged catfish was determined every two weeks, and feeding rate was adjusted after sampling the total population from each cage. All cages and ponds were harvested on 4 January 2006 by seining twice followed by complete draining. Final total number and weight of all fish

species in both cages and ponds were determined. Net fish yield (NFY) was calculated as $\text{g m}^{-2} \text{d}^{-1}$ by dividing the difference between total initial and final fish biomass per pond by the surface area of the pond and trail period. Based on the quantity of feed fed and NFY, food conversion ratio (FCR) of caged catfish, and combined caged catfish and open-pond carps were calculated by dividing the amount of total feed consumed by NFY.

A simple economic analysis was conducted based on farm-gate prices for harvested fish and market prices for all costs in Nepal (Shang, 1990). Farm gate prices of African catfish and carps were 120 and 100 NRs/kg (\$1 US = 71 NRs), respectively. Prices for African catfish and carps fingerlings were 5 and 0.25 NRs/piece, respectively. Prices for feed, DAP and urea were 15, 28 and 18 NRs/kg, respectively. The price for a cage was 1200 NRs, and it was expected to last for 3 years (6 culture cycles). The calculation for cost of working capital was based on an annual interest rate of 8%.

Data were analyzed statistically by two way analysis of variance (ANOVA) using SPSS (version 11.0) statistical software package (SPSS Inc., Chicago, USA), considering site as block. Differences were considered significant at the 95% confidence level ($P < 0.05$). All means were given with \pm standard error (S. E.).

RESULTS

Catfish survival was relatively low (only about 70%) over the first 15 days of culture (Figure 2), then stabilized, and overall survival for the 164-day experiment was 54.9% (Table 1). Yields from cages were quite low, with a biomass of 23.1 kg/cage, gross yield of 23.21 kg/cage, and net yield of 20.6 kg/crop (Table 1). FCR was quite high (2.8). Mean size at harvest for catfish was relatively large at 212.7 g. African catfish grew steadily and slowly at about 1.3 g/d during the entire culture period (Figure 1).

Mean total weight, harvest size, weight gain, gross and net fish yields of silver and bighead carps in the control were significantly higher than in the cage treatment ($P < 0.05$), while there were no significant differences in growth and production of common carp, rohu and mrigal between the control and cage treatment ($P > 0.05$; Table 2). The net and gross yields of carps in the control were significantly higher than in the cage treatment ($P < 0.05$; Table 2), however, the combined net and gross yields of catfish and carps were significantly higher in the cage treatment than for carps alone in the control ($P < 0.05$; Table 3). The combined overall FCR of catfish and carps in the cage treatment was 1.8 ± 0.2 , while the FCR for catfish alone was 2.8 ± 0.2 (Tables 1 and 3).

Water temperature was high (29-32°C) during the initial period of the experiment, and decreased continually to about 17°C at the end of the experiment (Figure 3). The pH was slightly alkaline (8-9) during the whole period of the experiment and fluctuated only slightly (Figure 4).

Gross revenue and total operational cost were significantly higher in the cage treatment than in the control ($P < 0.05$; Table 4). Both the control and cage treatment produced positive net returns, and the net return in the cage treatment was significantly higher than that in the control ($P < 0.05$; Table 4).

DISCUSSION

The daily weight gain of African catfish in the present experiment was $1.3 \text{ g fish}^{-1} \text{day}^{-1}$, which was lower than in outdoor cement tanks ($1.1\text{-}1.7 \text{ g fish}^{-1} \text{day}^{-1}$, Yi et al., 2004; and $1.7\text{-}1.9 \text{ g fish}^{-1} \text{day}^{-1}$, Long and Yi, 2004), an integrated pen-cum-pond system ($2.5\text{-}2.6 \text{ g fish}^{-1} \text{day}^{-1}$, Yi et al., 2003), and integrated cage-cum-pond system ($2.1\text{-}2.2 \text{ g fish}^{-1} \text{day}^{-1}$, Lin and Diana, 1995), but higher than those in two other integrated cage-cum-pond systems ($0.7 \text{ g fish}^{-1} \text{day}^{-1}$, Uddomkarn, 1989; $0.8\text{-}0.9 \text{ g fish}^{-1} \text{day}^{-1}$, Ye, 1991). The main reason of lower daily weight gains in this experiment was probably the low water temperature throughout the experimental period. Feed conversion ratio of African catfish (2.8 ± 0.2) in the present experiment was poorer than those reported in the above integrated

systems, that is, 1.2 by Yi et al. (2004), 1.5-1.7 by Ye (1991), 1.9-2.2 by Lin and Diana (1995), 1.1-1.2 by Long and Yi (2004), and 1.3 by Yi et al., (2003), but comparable to 2.8 reported by Uddomkarn (1989). Survival of African catfish ($54.9 \pm 1.0\%$) was lower than those reported by Uddomkarn (1989), Yi et al. (2004), Ye (1991) and Long and Yi (2004). The lower survival rate was probably due to the small stocking size and cannibalism among the fishes. Net fish yield (10.3 kg m^{-3}) of African catfish was lower than those ($14.3\text{-}28.7 \text{ kg m}^{-3}$) reported by Rai and Lin (1999).

African catfish grew steadily during the entire culture period. The water temperature measured during the experimental period remained below the favorable range for African catfish (Boyd, 1990), suggesting that the low water temperature limited growth performance during the most part of the experimental period.

Average gross and net fish yields of carps in the control ponds were greater than those in the cage treatment ponds, and this is probably the result of higher fertilization rates in the control than the waste loading rates in the cage treatment. The lower yield of carps in the cage treatment ponds was most likely due to poor growth of phytoplankton production caused by inadequate nutrient released from caged catfish wastes (Rai and Lin, 1999).

Both the control and cage treatment produced positive net returns ranging from 1,252 NRs/100 m² ponds in the control, and 1,859 NRs/100 m² pond in the cage treatment. There was also a significant increase in net returns for the integrated cage-cum-pond culture system as compared to the semi-intensive culture of carps alone. Small farmers having a single pond can produce high-valued fish for sale from cages and carps without feeding in ponds for home consumption as well as for sale. This increased production per unit area as well as income by 1.5 times the normal pond culture of carps in Nepal.

The results of the present experiment showed that African catfish has potential to be cultured in an integrated cage-cum-pond culture system, but it is necessary to avoid the winter season for culture. Also, growth and production of African can be improved by stocking larger fingerlings and by providing higher quality feed.

ANTICIPATED BENEFITS

This technology will be further improved and adopted to the local conditions in Nepal and will provide small-scale rural farmers an opportunity to generate more income and improve their livelihood using their scarce resources. As such, it will benefit small-scale rural farmers in Asia and other countries where integrated systems are practiced.

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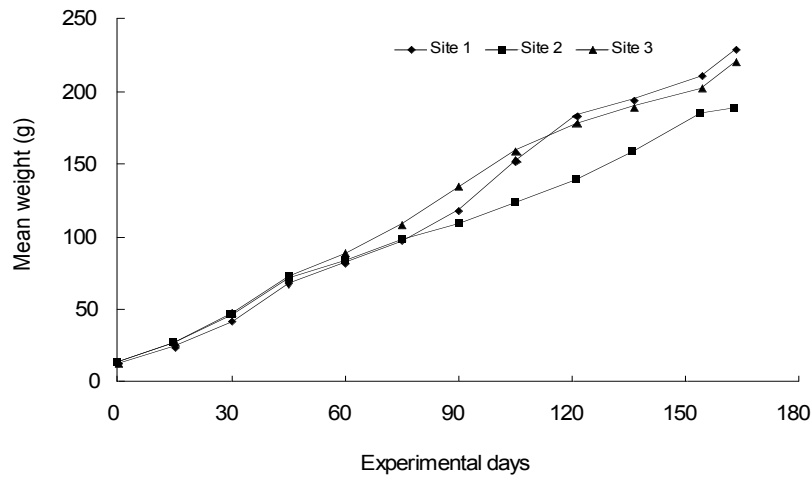


Figure 1. Growth of African catfish in cages suspended in ponds at different sites throughout the experimental period.

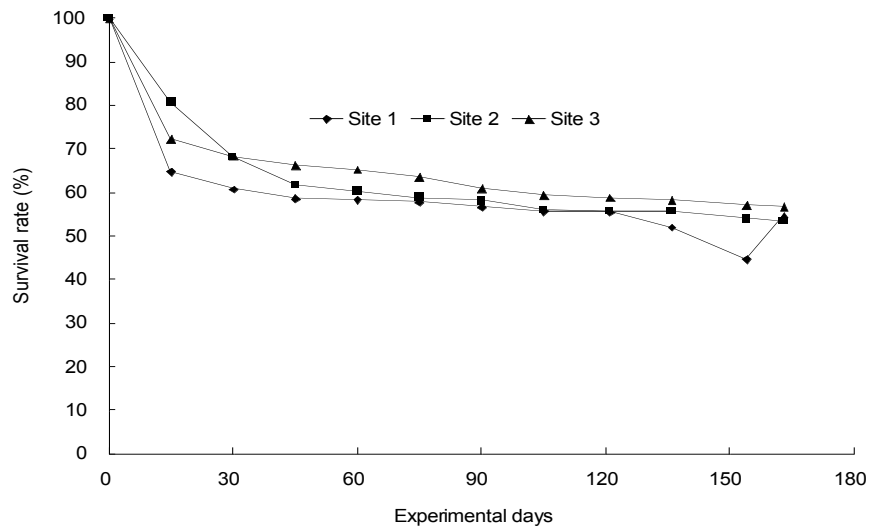


Figure 2. Overall survival of African catfish in cages suspended in ponds at different sites throughout the experimental period.

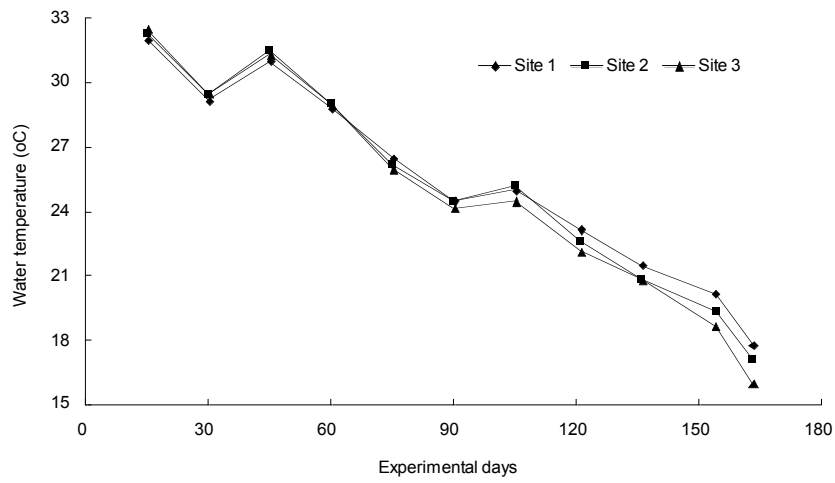


Figure 3. Changes in water temperature for ponds at different sites throughout the experimental period.

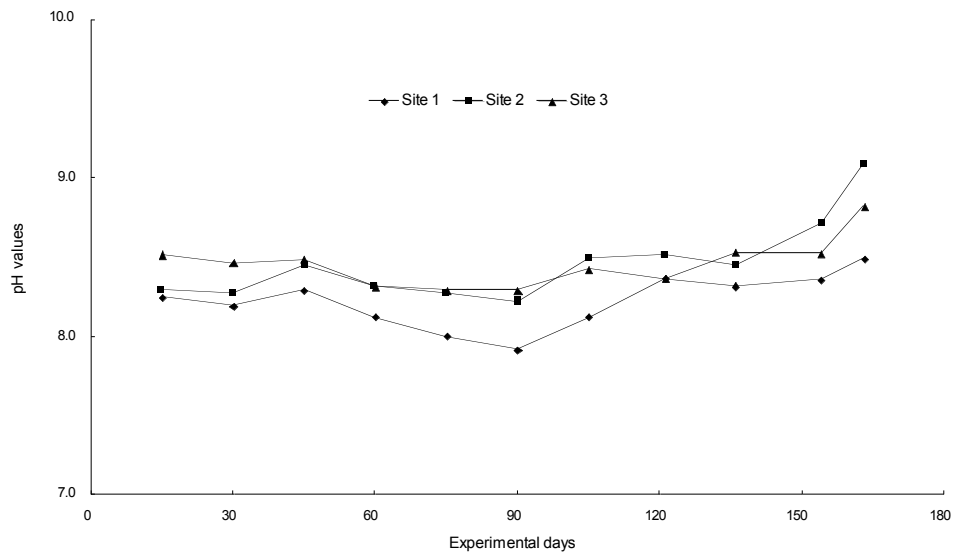


Figure 4. Changes in pH values for ponds at different sites throughout the experimental period.

Table 1. Values at stocking and harvest for size, weight gain, NFY, GFY, survival and FCR of caged African catfish in different sites.

Parameters	Sites			
	Site 1	Site 2	Site 3	Average
STOCKING				
Total weight (kg cage ⁻¹)	2.6±0.0	2.6±0.0	2.6±0.0	2.6±0.0
Mean weight (g fish ⁻¹)	12.8±0.0	13.2±0.0	13.2±0.0	13.1±0.1
HARVESTING				
Total weight (kg cage ⁻¹)	25.4±5.0	19.0±2.3	25.0±3.7	23.1±2.1
Mean weight (g fish ⁻¹)	229.0±29.5	188.5±24.3	220.6±5.1	212.7±12.3
Weight gain (g f ⁻¹ d ⁻¹)	1.4±0.18	1.2±0.15	1.4±0.03	1.3±0.1
Gross yield (kg cage ⁻¹ crop ⁻¹)	25.4±5.0	19.0±2.3	25.0±3.7	23.1±2.1
Net yield (kg cage ⁻¹ crop ⁻¹)	22.9±5.0	16.4±2.3	22.3±3.7	20.5±2.1
Survival (%)	54.5±4.8	53.3±12.5	56.8±9.1	54.9±1.0
FCR	2.6±0.5	3.1±0.2	2.8±0.1	2.8±0.1

Table 2. Values at stocking and harvest for size, weight gain, gross fish yield, net fish yield and survival of carps in the control and cage treatments. Values based on 100 m² pond area during 164 days culture period.

Parameter	Control	Cage treatment
Common carp		
STOCKING		
Total wt. (kg pond ⁻¹)	0.1±0.0	0.1±0.0
Mean wt. (g fish ⁻¹)	4.2±0.0	4.2±0.0
HARVEST		
Total wt. (kg pond ⁻¹)	5.3±0.2 ^b	4.5±0.9 ^a
Mean wt. (g fish ⁻¹)	381.3±37.4	364.5±58.6
Weight gain (g f ⁻¹ d ⁻¹)	2.5±0.2	2.4±0.4
Gross yield (kg cage ⁻¹ crop ⁻¹)	0.51±0.01	0.42±0.09
Net yield (kg cage ⁻¹ crop ⁻¹)	0.49±0.01	0.41±0.09
Survival (%)	71.2±5.1	65.0±10.0
Silver carp		
STOCKING		
Total wt. (kg pond ⁻¹)	0.2±0.0	0.2±0.0
Mean wt. (g fish ⁻¹)	4.6±0.0	4.6±0.0
HARVEST		
Total wt. (kg pond ⁻¹)	5.4±0.4 ^b	3.6±1.0 ^a
Mean wt. (g fish ⁻¹)	244.4±21.2 ^b	171.1±29.1 ^a
Weight gain (g f ⁻¹ d ⁻¹)	1.6±0.1 ^b	1.1±0.2 ^a
Gross yield (kg cage ⁻¹ crop ⁻¹)	0.51±0.03 ^b	0.34±0.10 ^a
Net yield (kg cage ⁻¹ crop ⁻¹)	0.50±0.03 ^b	0.32±0.10 ^a
Survival (%)	55.1±1.8	50.3±6.5
Bighead carp		
STOCKING		
Total wt. (kg pond ⁻¹)	0.04±0.00	0.04±0.00
Mean wt. (g fish ⁻¹)	2.2±0.0	2.2±0.0

Table 2 (continued)

Parameter	Control	Cage treatment
HARVEST		
Total wt. (kg pond ⁻¹)	3.6±0.1 ^b	2.7±0.6 ^a
Mean wt. (g fish ⁻¹)	234.9±21.6 ^b	183±27.3 ^a
Weight gain (g f ⁻¹ d ⁻¹)	1.5±0.1 ^b	1.2±0.2 ^a
Gross yield (kg cage ⁻¹ crop ⁻¹)	0.35±0.01	0.24±0.06
Net yield (kg cage ⁻¹ crop ⁻¹)	0.34±0.01	0.23±0.06
Survival (%)	79.1±7.0	71.1±11.1
Rohu		
STOCKING		
Total wt. (kg pond ⁻¹)	0.01±0.00	0.01±0.00
Mean wt. (g fish ⁻¹)	0.5±0.0	0.5±0.0
HARVEST		
Total wt. (kg pond ⁻¹)	0.9±0.1	0.8±0.3
Mean wt. (g fish ⁻¹)	120.2±10.2	111.4±27.4
Weight gain (g f ⁻¹ d ⁻¹)	0.8±0.1	0.7±0.2
Gross yield (kg cage ⁻¹ crop ⁻¹)	0.09±0.01	0.08±0.03
Net yield (kg cage ⁻¹ crop ⁻¹)	0.09±0.01	0.08±0.03
Survival (%)	73.5±2.5	72.2±4.0
Mrigal		
STOCKING		
Total wt. (kg pond ⁻¹)	0.01±0.00	0.01±0.00
Mean wt. (g fish ⁻¹)	0.7±0.0	0.7±0.0
HARVEST		
Total wt. (kg pond ⁻¹)	0.8±0.1	0.6±0.2
Mean wt. (g fish ⁻¹)	109.8±14.2	92.3±18.3
Weight gain (g f ⁻¹ d ⁻¹)	0.7±0.1	0.6±0.1
Gross yield (kg cage ⁻¹ crop ⁻¹)	0.08±0.01	0.06±0.02
Net yield (kg cage ⁻¹ crop ⁻¹)	0.08±0.01	0.06±0.02
Survival (%)	73.2±4.2	68.9±6.8

Mean values with different superscript letters in the same row were significantly different (P<0.05).

Table 3. Mean combined gross and net fish yields, survival and overall food conversion ratio of catfish and carps in the control and cage treatment.

Parameters		Control	Cage treatment
Gross fish yield (kg/pond)	Catfish	-	23.1±2.1
	Carps	15.3±0.5 ^b	11.5±2.9 ^a
	Combine	15.3±0.5 ^a	34.6±4.5 ^b
Net fish yield (kg/pond)	Catfish	-	20.6±2.1
	Carps	15.0±0.5 ^b	11.2±2.5 ^a
	Combine	15.0±0.5 ^a	31.0±3.5 ^b
Survival (%)	Catfish	-	54.9±1.0
	Carps	70.3±1.7 ^a	65.6±6.2 ^a
Overall FCR		-	1.8±0.2

Mean values with different superscript letters in the same row were significantly different (p<0.05)

Table 4. Economic analysis (in NRs) of control and caged ponds of 100 m² size during 164 days culture period.

Parameter	Control	Caged treatment
GROSS REVENUE PER POND PER CROP		
CATFISH	0	2777.9±247.1
Carps	1530.0±48.2 ^a	1221.1±282.2 ^a
Total	1530.0±48.2^a	3999.0±486.8^b
OPERATIONAL COST PER POND PER CROP		
Catfish fingerlings	0	1000.0±0.0
Carp fingerlings	25.0±0.0 ^a	25.0±0.0 ^a
Urea	57.2±0.0	0
DAP	186.0±0.0	0
Feed	0	840.8±54.1
Cage depreciation	0	200.0±0
Working capital cost (8%)	9.6±0.0 ^a	74.2±1.9 ^b
Total	277.8±0.0^a	2140.1±56.0^b
Net Return per Pond per crop	1252.2±48.2^a	1858.9±436.3^b

INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS WITH HIGH-VALUED FISH SPECIES IN CAGES AND LOW-VALUED SPECIES IN OPEN PONDS: CLIMBING PERCH (*ANABAS TESTUDINEUS*) AND NILE TILAPIA (*OREOCHROMIS NILOTICUS*) IN VIETNAM

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Final Report

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ABSTRACT

This on-farm trial was carried out in three districts of Vietnam (Tam Binh district of Vinh Long province, Thot Not district of Can Tho city, and Vi Thuy district of Hau Giang province) to adopt the integrated cage-cum-pond systems to local conditions. Five farmers' earthen ponds of 100 m² in surface area were selected in each of the three sites for the on-farm trial. Nile tilapia (*Oreochromis niloticus*) fingerlings (8-10 g size) were stocked at 2 fish m⁻² in all ponds, while climbing perch (*Anabas testudineus*) fingerlings (8-10 g size) were stocked in a 4-m³ cage suspended in each treatment pond. Stocking density of climbing perch was the treatment variable and was 50, 100, 150, and 200 fish m⁻³, giving caged climbing perch to open-pond Nile tilapia ratios of 1:1, 2:1, 3:1, and 4:1. There were also control ponds without a cage (0:1), and control ponds were fertilized weekly with urea and diammonium phosphate (DAP) at 28 kg N and 7 kg P ha⁻¹ week⁻¹. No fertilizer was added into treatment ponds. Pelleted feeds containing 32%, 26-28%, and 22% crude protein were given twice daily to caged climbing perch during the first, second and remaining months at rates of 5%, 3% and 2% body weight per day, respectively.

Survival of climbing perch, ranging from 85.5% to 91.1%, was not significantly different among sites and treatments. Daily weight gain (0.28 g fish⁻¹ day⁻¹) of climbing perch was significantly higher in the 1:1 ratio treatment than those (0.16 – 0.17 g fish⁻¹ day⁻¹) in the other treatments (P<0.05), among which there were no significant differences (P>0.05). Total harvested climbing perch biomass, ranging from 8.77 to 23.7 kg cage⁻¹, and increased with increasing stocking ratio of climbing perch to Nile tilapia (P<0.05). Feed conversion ratio (FCR) was lowest in the 4:1 ratio treatment, intermediate in the 1:1 and 3:1 ratio treatments and highest in the 2:1 ratio treatment (P<0.05). Survival of Nile tilapia was highest (93.0%) in the 3:1 ratio treatment, intermediate (86.8%-89.3%) in the 0:1, 1:1, and 2:1 ratio treatments, and lowest (84.0%) in the 4:1 ratio treatment (P<0.05). Growth of Nile tilapia, ranging from 1.17 to 1.78 g fish⁻¹ day⁻¹, was not significantly different among treatments (P>0.05), while the total harvested tilapia biomass was highest in the 3:1 ratio treatment, intermediate in the 1:1, 2:1 and 4:1 treatments, and lowest in the 0:1 ratio treatment (control) (P<0.05). Treatments with higher ratios (3:1 and 4:1) gave higher net revenues (0.374 and 0.361 million VND per 100 m² pond). The on-farm trial has demonstrated that the high-valued climbing perch may provide potential for the integrated cage-cum-pond culture system, but it is necessary to improve FCR of climbing perch in order to increase the profitability of the system.

INTRODUCTION

Integrated cage-cum-pond culture is a system in which high-valued fish species are fed with artificial diets in cages suspended in ponds, while filter-feeding fish species are stocked in open pond water to utilize natural foods derived from cage wastes. This integrated system has been developed and practiced using combinations of catfish-tilapia (Lin, 1990; Lin and Diana, 1995) and tilapia-tilapia (Yi et al., 1996; Yi, 1997; Yi and Lin, 2000, 2001). Although cages in the work mentioned above were set up in monoculture ponds for Nile tilapia (*Oreochromis niloticus*), this integrated system can also be applied in polyculture systems. In polyculture, ponds are stocked with several species of different feeding habits. It is impossible to target feeding high-valued species in polyculture ponds, because low-valued species can also consume the feed, resulting in economic inefficiency unless a caged system is adopted. Compared to nutrient utilization efficiency of about 30% in most intensive culture systems (Beveridge and Phillips, 1993; Acosta-Nassar et al., 1994), the nutrient utilization efficiency could reach more than 50% in integrated cage-cum-pond systems, resulting in the release of much less nutrients to receiving waters (Yi, 1997).

Rural pond aquaculture in Vietnam is mainly semi-intensive carp polyculture of both Indian major and Chinese carps with low average production. Poor farmers have limited financial resources to dedicate their whole ponds to culture a single high-valued species using expensive artificial feed. The integrated cage-cum-pond system provides an opportunity for small-scale farmers to use their limited resources to include some high-valued species in their ponds, to generate more income and improve their livelihood. This will allow them to improve nutrient utilization efficiency, sell high-valued species, and reduce fertilizer cost, because the open pond water can utilize cage wastes as fertilizer for lower-valued species. This integrated system is environmentally friendly because less waste nutrients are released to receiving waters.

Climbing perch (*Anabas testudineus*) is distributed widely in both fresh and brackish water in many Asian countries, and it is highly esteemed for its highly nourishing quality and prolonged freshness out of water (Besra, 2000). Although climbing perch has been described as omnivorous, it has a tendency toward carnivory (Besra, 2000). In southern Vietnam, climbing perch is an indigenous species with high market value, and can be cultured in cages at high density, due to its air-breathing ability. Climbing perch may be a suitable species for stocking cages in order to develop an integrated cage-cum-pond culture system in Vietnam.

This study was a follow-up to a previous on-station trial conducted in 2004 in O Mon district of Can Tho City with similar experimental design. The overall objective of the study was to evaluate integration of high-valued fish cultured in cages and low-valued fish cultured in open pond water in terms of fish growth and economic return. The specific objective was to evaluate effects of different stocking ratios of climbing perch in cages and Nile tilapia in open pond water on fish growth, productivity and economics of the system at farm level.

MATERIALS AND METHODS

An experiment was conducted in three sites including Tam Binh district of Vinh Long province, Thot Not district of Can Tho City, and Vi Thuy district of Hau Giang province for five months, from April to September 2005.

The experiment was conducted in 15 earthen ponds of 100 m² each, where 12 ponds included one net cage of 4 m² (2x2x1.5 m). Cages were made of metal frames covered with net, supported by four vertical bamboo poles for each cage, and suspended 20 cm above pond bottom. Water level was kept at 1.2 m in ponds and 1 m in cages by adding water regularly. Pond dykes were fenced by mosquito net, which was 50 cm high to prevent fish escape from ponds and entry of unwanted animals into ponds.

The experiment was conducted with different stocking ratios of climbing perch including 50, 100, 150, and 200 fish · m⁻³ in cages, while Nile tilapia were stocked at 2 fish · m⁻² in open water of all ponds, giving climbing perch to Nile tilapia ratios of 1:1, 2:1, 3:1, and 4:1 as four treatments, respectively. There was also a control without cage (0:1), and control ponds were fertilized weekly with urea and diammonium phosphate (DAP) at 28 kg N and 7 kg P ha⁻¹ week⁻¹. The experiment was set-up using randomized block design approach where each study site had one replication of each treatment.

Both climbing perch and Nile tilapia fingerlings of 8-10 g in size were collected from nursing ponds. Nile tilapia fingerlings were stocked one week after stocking climbing perch. The control ponds were fertilized to stimulate growth of natural foods one week prior to stocking Nile tilapia.

Caged climbing perch were fed floating commercial pelleted feeds at 0800 and 1600 h daily contained 32%, 26-28% and 22% crude protein and were applied at 5%, 3% and 2% body weight per day for the first month, second month and the remainder of the experimental period, respectively. Feeding rates were adjusted monthly based on sampling weight and observed mortality of climbing perch. Climbing perch were sampled monthly by randomly selecting 30 fish that were weighed individually, while all Nile tilapia were weighed and counted at stocking and harvest only. No feed was given to Nile tilapia, and no fertilizers were applied to the treatment ponds with cages. Water temperature, pH, total ammonia nitrogen (TAN) and nitrite nitrogen (NO₂-N) were measured monthly using thermometer, pH meter (ORION model 230A, USA), and test kits (SERA, Germany).

Data were analyzed statistically by two-way analysis of variance (ANOVA) using SPSS (version 11.0) statistical software package (SPSS Inc., Chicago, USA), considering site as block. Differences were considered significant at 95% confidence level ($p < 0.05$). All means were given with \pm standard deviation.

RESULTS

Average water temperature and pH were not significantly different among treatments ($P > 0.05$), ranging from 28.0°C to 28.2°C and from 7.04 to 7.19, respectively. With increasing stocking ratio of climbing perch to Nile tilapia, total ammonia nitrogen concentration increased from 0.01 mg L⁻¹ to 0.42 mg L⁻¹ (Table 1).

Average survival rate of climbing perch in cages was high in all treatments, ranging from 85.5% to 91.1%, and no significant difference was found among treatments ($P > 0.05$; Table 2). Climbing perch grew steadily in all treatments (Figure 1), and average mean weight at harvest was highest in the 50 fish m⁻³ (1:1 ratio) treatment, intermediate in the 100 fish m⁻³ treatment, and lowest in the 150 and 200 fish m⁻³ treatments ($P < 0.05$; Table 2). Net fish biomass increased with increasing stocking density of climbing perch ($P < 0.05$; Table 2). Feed conversion ratio (FCR), ranging from 4.02 to 8.25, was high in all treatments, and was best in the treatment with highest stocking density ($P < 0.05$; Table 2).

Survival rate of Nile tilapia in open pond was high, ranging from 84.0% to 93.0%. Survival rate was highest in the 3:1 ratio treatment, intermediate in the control and the 1:1, 2:1 and lowest in the 4:1 ratio treatments ($P < 0.05$; Table 3). There were no significant differences in mean weight at harvest and daily weight gain among treatments ($P > 0.05$). Gross and net yields were highest in the 3:1 ratio treatment, intermediate in the 1:1, 2:1 and 4:1 ratio treatments, and lowest in the control ($P < 0.05$; Table 3).

The combined gross and net yields of both climbing perch and Nile tilapia ranged from 10.9 to 16.4 t ha⁻¹ year⁻¹ and from 10.0 to 14.6 t ha⁻¹ year⁻¹, respectively, which were significantly higher than those (7.3 and 6.9 t ha⁻¹ year⁻¹) of Nile tilapia alone control ponds ($P < 0.05$; Table 4). The combined gross and net yields were highest in the 3:1 and 4:1 ratio treatments, intermediate in the

1:1 and 2:1 ratio treatment, and lowest in the control ($P < 0.05$; Table 4). The overall FCR, ranging from 1.03 to 1.44, were not significantly different among treatments ($P > 0.05$; Table 4).

Feed cost for caged climbing perch accounted for the highest portion of total cost. The integrated cage-cum-pond culture treatments showed significantly higher gross incomes than the control, and the 3:1 and 4:1 ratio treatments had the highest gross incomes of 1.2 million VND (\$1US = 15,980 VND) for 100 m² pond (Table 5). The net incomes were not significantly different among treatments, but showed similar trends.

DISCUSSION

Measured water quality parameters in all ponds were within the normal range for culture of most fish species (Boyd, 1998). The values of pH ranging from 7.04 to 7.19 are near the lower limit of the range for the optimal growth of warmwater species, which is 7-9 (Boyd, 1998). The low pH occurred because culture was conducted during the rainy season (April to September) in the Mekong delta. Total ammonia nitrogen increased with increasing stocking density of climbing perch, due to the increased feeding application to caged climbing perch and thus increased waste loading to the ponds.

The survival rate of climbing perch was 85.5% to 91.1%, which was lower than those (97.1% - 99.6%) found by Yi *et al.* (2005) in a previous experiment conducted in the Mekong delta. However, it was higher than the survival rates of climbing perch cultured in ponds, which ranged from 74.4% to 83.5% at stocking densities of 25-40 fish m⁻² (Long *et al.*, 2006; Phu *et al.*, 2006). Lin *et al.* (1989) and Lin (1990) reported that the survival rate of air-breathing hybrid catfish (*Clarias macrocephalus* x *C. gariepinus*) ranged from 54%-92% in an integrated cage-cum-pond culture system.

Final mean weight of climbing perch reached good marketable size (>50 g) after 150 days of culture at the stocking density of 50 fish m⁻³. This size, though small by standards for other species, can fetch the highest market price. Final mean weight of climbing perch in other cage-cum-pond treatments was at normal range of market sizes (32.8-34.3 g). Phu *et al.* (2006) reported that climbing perch size reached 55-56 g after 150 days at a stocking density of 25 fish m⁻² in pond culture, while Long *et al.* (2006) reported that climbing perch reached 46-49 g at higher stocking densities of 30-40 fish m⁻² in pond culture over 150 days. Similar trends in daily weight gain were found in these two studies. The stocking density of climbing perch up to 150-200 fish m⁻³ did not affect the growth but increased production (Long *et al.*, 2006).

FCR in all treatments of the present experiment, ranging from 4.02 to 8.25, was very high, possibly because the pelleted feed we used was not designed for climbing perch or the feeding scheme of gradually reducing protein content in diet was not suitable for climbing perch. Phu *et al.* (2006) reported that FCR of climbing perch fed diets containing 23%, 26% and 32% crude protein during culture period was 3.08, 3.19 and 2.83, respectively. In addition, Putra (1993) stated that FRC of climbing perch is rather high compared to other tropical fishes, which often achieve an FCR near 10.

Tilapia growth in the control and treatment ponds was relatively low, with daily weight gain ranging 1.17 to 1.78 g fish⁻¹. These values are intermediate between typical fertilized systems (about 1 g d⁻¹) and fed systems (about 3 g d⁻¹; Diana *et al.*). Final mean weights of tilapia were 176-268 g, which was comparable to that from fertilized ponds. The results obtained from this experiment were much better than the similar experiment conducted in 2004 (Yi *et al.* 2005) in which tilapia size at harvest ranged from 104 to 134 g and daily weight gain was only 0.61 - 0.86 g fish⁻¹. These higher weight gains were probably due in part to the high FCR for climbing perch and the release of feed to the ponds.

Tilapia played a significant role in improving the productivity and overall feed utilization efficiency in the integrated cage-cum-pond culture system by reusing the wastes derived from

cages. The combined gross and net yields of both climbing perch and Nile tilapia were to 10.9 – 16.4 and 10.0 – 14.6 t ha⁻¹ year⁻¹, respectively, which is higher than those obtained from ponds with fertilization alone and similar to those with supplemental feeds. Climbing perch culture has high FCR even in pond culture, thus the integrated cage-cum-pond culture system can recover nutrients from the cage wastes and reduce environmental pollution caused by intensive fish culture.

This study has demonstrated that the high-valued climbing perch may provide potential for integrated cage-cum-pond culture system, but it is necessary to improve FCR of climbing perch in order to improve the profitability of the systems.

ANTICIPATED BENEFITS

This technology can eventually provide small-scale rural farmers an opportunity to generate more income and improve their livelihood using their scarce resources, and will benefit small-scale rural farmers in countries where the integrated systems are practiced.

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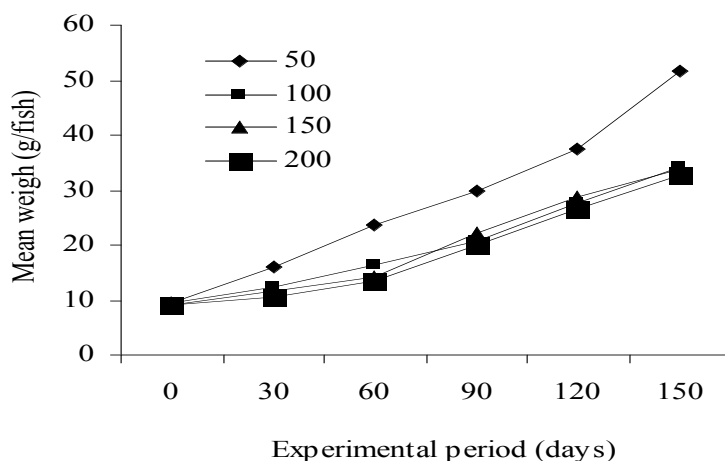


Figure 1. Growth of climbing perch during 150 days of culture.

Table 1. Mean (ISD) values of water quality in each treatment.

Parameters	Stocking ratio of climbing perch to Nile tilapia				
	0:1	1:1	2:1	3:1	4:1
Temperature (°C)	28.1±0.12	28.2±0.06	28.0±0.03	28.1±0.08	28.1±0.14
pH	7.19±0.31	7.14±0.07	7.04±0.06	7.13±0.10	7.16±0.06
TAN (mg/L)	0.14±0.02	0.01±0.02	0.18±0.01	0.14±0.01	0.42±0.33
NO ₂ -N (mg/L)	0.02±0.00	0.02±0.01	0.04±0.05	0.03±0.03	0.03±0.02

Table 2. Growth performance of climbing perch in cages after 150 days of experimental period.

Parameters	Stocking ratio of climbing perch to Nile tilapia			
	1:1	2:1	3:1	4:1
Stocking				
Initial weight (g fish ⁻¹)	9.47±0.51	9.42±0.29	9.02±0.40	9.07±0.15
Initial biomass (kg cage ⁻¹)	1.9±0.10 ^a	3.8±0.12 ^b	5.4±0.24 ^c	7.2±0.12 ^d
Stocking density (fish m ⁻³)	50	100	150	200
Harvest				
Average weight (g fish ⁻¹)	51.5±9.22 ^a	34.3±8.20 ^{ab}	33.6±3.13 ^b	32.8±2.50 ^b
Daily weight gain (g fish ⁻¹ day ⁻¹)	0.28±0.06 ^a	0.17±0.05 ^b	0.16±0.02 ^b	0.16±0.02 ^b
Harvest biomass (kg cage ⁻¹)	8.8±1.33 ^a	12.5±2.89 ^b	18.0±1.15 ^c	23.7±1.15 ^d
Harvest biomass (kg m ⁻³)	2.19±0.33 ^a	3.12±0.72 ^b	4.49±0.29 ^c	5.92±0.29 ^d
Net biomass (kg cage ⁻¹)	6.9±1.41 ^a	8.7±2.77 ^b	12.6±0.93 ^c	16.4±1.17 ^d
Net biomass (kg m ⁻³)	1.7±0.35 ^a	2.2±0.69 ^b	3.1±0.23 ^c	4.1±0.32 ^d
Survival rate (%)	85.5±5.29	91.1±3.66	89.2±4.48	90.5±3.96
FCR	6.24±1.06 ^{ab}	8.25±1.92 ^a	5.43±0.16 ^{bc}	4.02±0.23 ^c

Mean values with different superscript letters in the same row were significantly different (P<0.05).

Table 3. Growth performance of Nile tilapia in open pond water after 150 days of experimental period.

Parameters	Stocking ratio of climbing perch to Nile tilapia				
	0:1	1:1	2:1	3:1	4:1
Stocking					
Initial weight (g fish ⁻¹)	10.0±0.2	10.2±0.2	10.2±0.2	10.1±0.4	10.3±0.1
Initial biomass (kg pond ⁻¹)	2.0±0.04	2.0±0.03	2.0±0.03	2.0±0.08	2.1±0.02
Density (fish m ⁻²)	2	2	2	2	2
Harvest					
Average weight (g fish ⁻¹)	176±8.3	206±26.6	236±45.8	268±50.6	251±90.3
DWG (g fish ⁻¹ day ⁻¹)	1.17±0.06	1.35±0.22	1.57±0.31	1.78±0.34	1.67±0.60
Harvest biomass (kg pond ⁻¹)	30.5±2.34 ^a	36.1±4.14 ^{ab}	42.4±9.39 ^{ab}	49.5±7.84 ^b	41.5±13.38 ^{ab}
Net biomass (kg pond ⁻¹)	28.5±2.33 ^a	34.1±4.15 ^{ab}	40.4±9.41 ^{ab}	47.5±7.79 ^b	39.4±13.39 ^{ab}
Gross yield (t ha ⁻¹ year ⁻¹)	7.4±0.57 ^a	8.8±1.01 ^{ab}	10.3±2.28 ^{ab}	12.0±1.91 ^b	10.1±3.25 ^{ab}
Net yield (t ha ⁻¹ year ⁻¹)	6.9±0.57 ^a	8.3±1.01 ^{ab}	9.8±2.29 ^{ab}	11.6±1.90 ^b	9.6±3.26 ^{ab}
Survival rate (%)	86.8±6.01 ^{ab}	87.7±2.52 ^{ab}	89.3±2.89 ^{ab}	93.0±5.00 ^a	84.0±5.00 ^b

Mean values with different superscript letters in the same row were significantly different (P<0.05).

Table 4. Combined production of climbing perch and Nile tilapia in ponds after 150 days of experimental period.

Parameters	Stocking ratio of climbing perch to Nile tilapia				
	0:1	1:1	2:1	3:1	4:1
Initial biomass (kg pond ⁻¹)	2.0±0.04 ^a	3.9±0.10 ^b	5.8±0.09 ^c	7.4±0.31 ^d	9.3±0.14 ^e
Harvest biomass (kg pond ⁻¹)	30.5±2.34 ^a	44.9±5.30 ^{ab}	54.8±11.0 ^{bc}	67.5±8.79 ^c	65.2±14.0 ^c
Gross yield (t ha ⁻¹ year ⁻¹)	7.3±0.57 ^a	10.9±1.29 ^b	13.3±2.68 ^{bc}	16.4±2.14 ^c	15.9±3.40 ^c
Net yield (t ha ⁻¹ year ⁻¹)	6.9±0.57 ^a	10.0±1.31 ^{ab}	11.9±2.66 ^{bc}	14.6±2.07 ^c	13.6±2.41 ^c
Overall FCR	---	1.03±0.12	1.44±0.30	1.14±0.11	1.24±0.36

Mean values with different superscript letters in the same row were significantly different (P<0.05).

Table 5. Economic analysis of the integrated cage-cum-pond culture system for 150 days of culture period based on 100 m² pond area (in million VND).

Parameters	Stocking ratio of climbing perch to Nile tilapia				
	0:1	1:1	2:1	3:1	4:1
Total cost	0.060±0.000	0.432±0.002	0.658±0.023	0.809±0.031	0.889±0.001
Gross income	0.305±0.023	0.773±0.090	0.925±0.179	1.182±0.131	1.250±0.193
Net return	0.245±0.023	0.301±0.091	0.266±0.157	0.374±0.101	0.361±0.194

REPRODUCTIVE PERFORMANCE AND GROWTH OF IMPROVED TILAPIA*Twelfth Work Plan, Applied Technology & Extension Methods 2 (12ATE2)**Final Report**Published as Submitted by Contributing Authors*

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ABSTRACT

This study compared the growth, survival, sexual maturation and various reproductive parameters of four tilapia strains, three of which have been improved through various selective breeding approaches (GIFT, IDRC and Fishgen-selected) and a local stock (Chitralada) was included as a non-improved control. The four strains were originally cultured in extensive culture systems with fertilisation only. Growth (weight and length) and reproductive parameters (gonadosomatic index, hepatosomatic index, and stages of sexual maturation) were measured on fish sampled every 21 days. Based on staging of gonad development, GIFT were found to become sexually mature marginally later than the other two strains. At 9 months of age, broodstock from each strain were stocked in 5m² breeding hapas with 5 males and 15 females per hapa and four replicate hapas per strain. Broodstock were sampled for eggs every week and data collected on fecundity and inter-spawning interval for the four strains over the 17 months. Seasonal and environmental variances appear to be the major determinants of egg/fry production with the only strain difference observed being a lower relative fecundity in GIFT. Across all strains, fecundity per female increased over time while fecundity per unit weight of female remained constant. SF and ISIs fluctuated widely between individual fish, and ISIs were even highly variable within individual females making it very difficult to identify trends. Many females spawned very infrequently and means of identifying fecund females could have significant impacts upon hatchery efficiency.

INTRODUCTION

Significant progress in genetic improvement of cultured fish has been made in the last decade, including implementation of breeding programmes in species such as tilapias and carps used extensively in aquaculture in the developing world. There have, in particular, been a number of breeding programmes for tilapia, the best known of which is probably the Genetically Improved Farmed Tilapia (GIFT) project initiated by ICLARM (Eknath and Acosta, 1998). The problem of precocious sexual maturation and unwanted reproduction has promoted the widespread use of monosex fish in the industry but also raised a consciousness about sexual maturation and breeding not considered in the culture of most other species. Late maturation, and to a lesser extent reduced fecundity, are thus considered desirable traits by growers. These are however undesirable traits for hatchery producers. Given that tilapia is a low value species, profit margins on seed production can be relatively small. The extra cost of maintaining broodstock for a longer time before initiating seed production and thus maintaining larger fish as broodstock with higher resource requirements (feed and space) and greater difficulty in handling would dissuade many hatcheries from using a late maturing strain unless the selling price of the seed warrants it. This appears to be the case for GIFT tilapia in hatcheries in Thailand where anecdotal information from hatchery managers have indicated that this strain is indeed later maturing than alternative unimproved strains (Turner, pers. comm.). Later maturation has resulted in some hatcheries using

only GIFT males as broodstock, crossing those to earlier maturing females from a local strain, thus losing some of the potential benefit of the breeding program which has produced the GIFT. The GIFT available in Thailand apparently has not been selected for later maturation, and if later maturation and lower fecundity of this strain are confirmed, these might be considered correlated traits to growth. More rapid growth is considered positive to growers, but negative to hatcheries who carry the responsibility of supplying quality seed to the growers.

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

MATERIALS AND METHODS

Source of broodstock

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

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

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

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

The grow-out phase

Broodstock of Chitralada, Fishgen-selected and Philippine-selected (IDRC) were bred at AIT using standard methods of pooled spawning of broodstock in fine-mesh hapas (Bhujel, 2000) with a minimum of 12 spawning females providing the 4000 fry representative of each strain. The GIFT fry of the same age (maximum age difference across all fish was two weeks) were obtained from NAGRI. Fry from the different strains were nursed through three stages of nursing at standardized densities, in hapas suspended either in concrete tanks or an earthen pond, with densities reducing through each phase.

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

In a separate stocking trial, fish were stocked at 3 per m² in 3 replicate half ponds (100 m²) making 75 fish per strain per replicate (totaling six ponds, each divided into two with a fine mesh screen). Fish were grown for a period of 91 days, with 30 fish being sampled for weight and standard length every 21 days. In the later samplings, 20 fish per half pond were removed for determination of GSI and stage of sexual maturation, thereby reducing the overall stocking density of the ponds. All fish were weighed, measured, and sexed at harvest.

For the second trial in a communally stocked pond, randomly selected 6-week-old fish at mean weights of 15-22g were marked by fin clip and coded wire tags (Mair, 2002) and stocked together in a single 200 m² earthen pond (600 fish, 150 per strain). Sampling was as for the separately stocked trials and all fish were harvested after 85 days of grow-out.

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

Assessment of sexual maturation

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

Comparative evaluation of breeding

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

Eggs were collected from each hapa every seven days according to standard protocols developed at AIT (reviewed by Bhujel, 2000). Each female was tagged with a PIT tag at first spawning and all tag numbers of spawned females were recorded in subsequent collections along with the post-spawning weight, providing full breeding profiles for all spawning females in each hapa. Collected eggs were staged according to their development, weighed, and counted using volumetric estimation. Evaluation of reproduction in the strains is a continuous process and is ongoing. This is a preliminary presentation of data collected over 70 weeks representing production from fish in the age range of 6 to 22 months. A problem arose with collection of the data that while most females were tagged (only those that never spawned did not receive a tag), the total number of males and females in a hapa was not counted during the early part of the experiment. Also, some mortality occurred in broodstock over time, which affected the number of breeders remaining in the breeding hapa. These broodstock were replaced after 9 months of production, using spare stock that had been retained after harvest at the end of the growth phase and maintained in similar condition to the breeding fish. As a result of the omission of total counts of broodfish it was difficult compare overall productivity of the strains other than by preparing total counts factoring in both fecundity and survival parameters. Variables that could be calculated or estimated from the data included absolute and relative fecundity, spawning frequency and inter-spawn interval.

Data analysis

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

RESULTS

The grow-out phase

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

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

Assessment of sexual maturation

The results of the staging of sexual maturation of males and females of the four strains at harvest in the separate and communally stocked trials are shown in Figures 1 and 2 respectively.

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

Comparative evaluation of breeding

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

Fry production over the 70-week period was highly variable in production, but temporal variation in production seemed to be broadly common to all the strains.

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

Investigation of spawning frequency over the 70-week period revealed no significant differences between the strains with average spawning frequencies ranging between 5 and 7 (Figure 3).

Investigation of temporal trends in fecundity across all strains combined revealed that absolute fecundity increased with age of the fish, while relative fecundity appeared to remain constant although neither correlation was significant. A similar lack of correlation was observed between relative fecundity and the post-spawn weight of females.

DISCUSSION

These results shed some light on the debate over the relationship between growth and fecundity in tilapia and the impact of selection for growth on this relationship. The growth trials, although not a major element of this study, appear to confirm superior growth rates of the growth selected strains over the non-selected Chitralada although these differences were not significant in the replicated trial. The development of gonads was characterized in the strains at the end of the grow-out phase when the fish were at an age when about 50% of the fish might be expected to be sexually mature (Kronert et al., 1987) despite their relatively small size. The absence of the most mature males and females in GIFT provided some indication that this strain is later maturing than the other strains. The differences were not extreme and were not in accord with the GSI data from females in which it might have been expected (in non spawning fish) that a later maturing strain would have had an overall lower GSI. The timing of sexual maturation and the verification of anecdotal information from hatcheries regarding the late maturation of GIFT females clearly requires more substantive examination.

The data set developing from the long term comparative evaluation of breeding is perhaps unique in that it is tracing spawning patterns of individual fish and may enable us trace fecundity parameters of tilapia broodstock (focusing on females) throughout their productive life and help determine the optimum ages for using broodstock. There is huge variability in spawning patterns between individual females and over time. Environmental factors and variation between individual fish may be more important factors in hatchery productivity than is strain. However, there were some significant differences in fecundity between strains, with GIFT having overall lower fecundity than the other strains, supporting anecdotal evidence supplied by hatcheries. The

age-fecundity relationships are in line with expectations for absolute fecundity, although, relative fecundity might have been expected to decline with age, based on findings with other species, admittedly over larger age differences, (Siraj et al., 1983; Ridha and Vera Cruz, 1989). The lack of any relationship between female size (weight) and relative fecundity is also perhaps surprising given the findings of other authors (Srisakultiew, 1993).

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

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

ANTICIPATED BENEFITS

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

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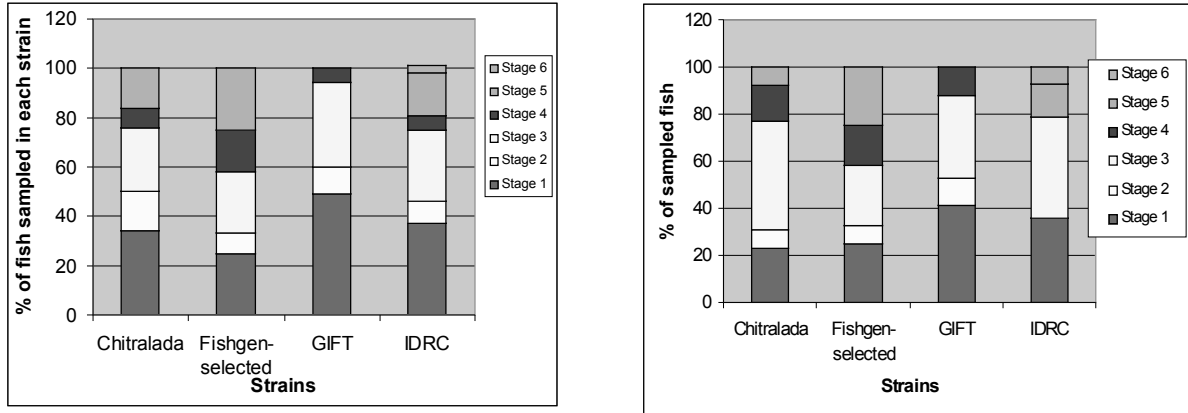


Figure 1. Stages of sexual maturation of males at harvest for fish from separately stocked (left – aged 119 days) and communally stocked (right – aged 127 days) growth comparisons.

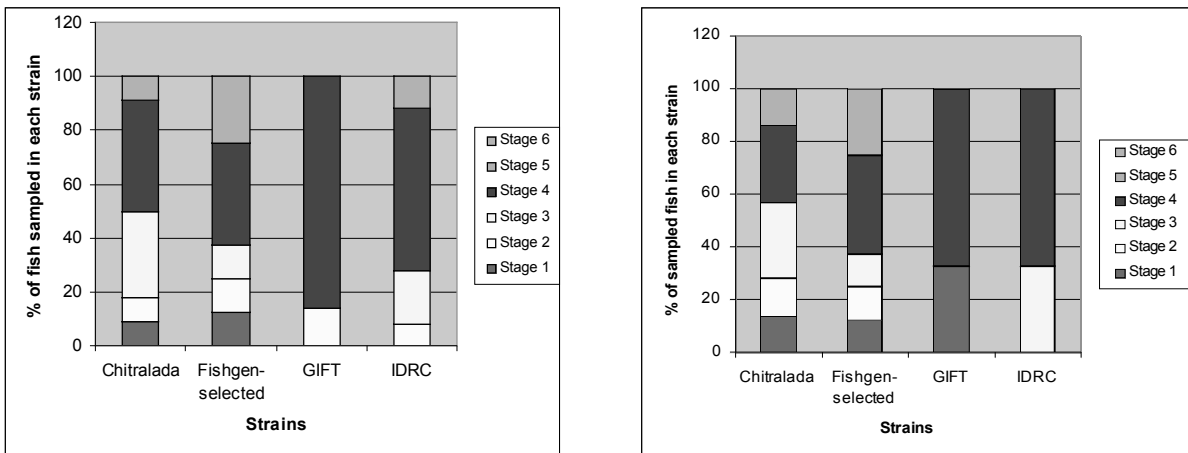


Figure 2. Stages of sexual maturation of females at harvest for fish from separately stocked (left – aged 119 days) and communally stocked (right – aged 127 days) growth comparisons.

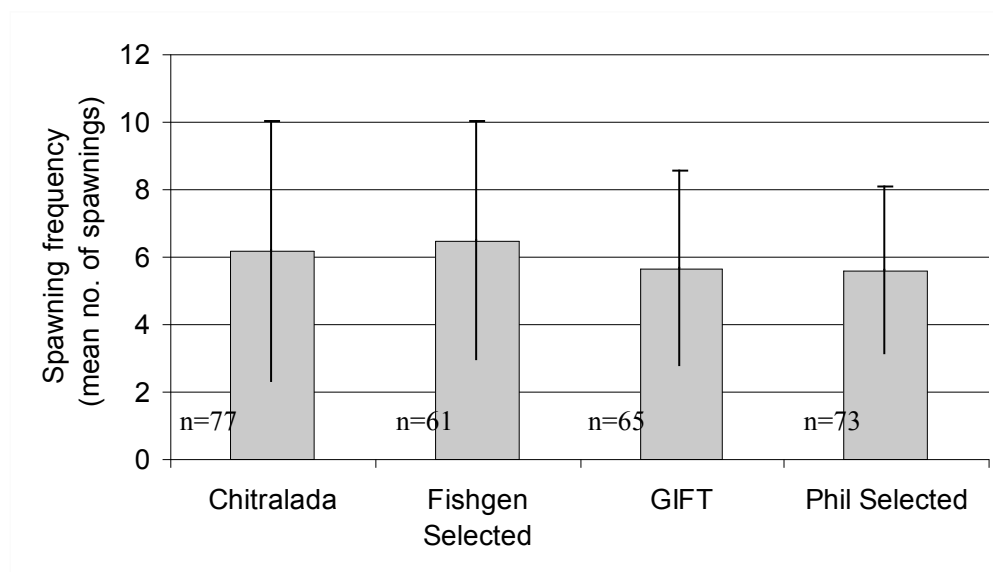


Figure 3. Comparison of mean spawning frequency of spawning females in the four strains over the 70-week evaluation period.

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

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

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

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

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

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Final Report

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ABSTRACT

The Aquaculture CRSP, the Moi University (MU) Department of Fisheries and Aquatic Sciences, and the Fisheries Department of the Government of Kenya (FD) have expended considerable effort on aquaculture training at various levels during the past decade (1997-2007). Target audiences for this training have included fish farmers, fisheries extension workers, undergraduate students, and graduate students. Training for fish farmers and extension workers has typically been conducted through farmer field days and two- and three-week short courses. Training for undergraduates typically has involved providing small stipends and supervision for “senior projects” in some aspect of aquaculture appropriate to Kenya. Training for graduate students has been done by providing scholarship support for formal degree programs, both abroad and at Kenyan Universities.

This investigation was undertaken to continue these training efforts in Kenya. Specific objectives have been to train up to 34 extension workers and 6 advanced farmers in hatchery management techniques, to provide on-farm training in simple techniques for spawning, hatching, and rearing African catfish (*Clarias gariepinus*) juveniles in ponds for up to 12 farmers, to provide stipend support for 4 undergraduate students studying aquaculture at MU, and to provide scholarship support for two Master’s-level (MSc) university students at MU. The focus of this set of activities has been on catfish aquaculture, particularly on developing improved fingerling production techniques and transmitting these new techniques to extension personnel and farmers.

All objectives of this investigation have been met. Two two-week short courses were given to selected FD Fisheries Assistants (extension workers), Kenya Marine and Fisheries Research Institute (KMFRI) technicians, and advanced fish farmers. The courses were held at Sagana and Moi University, on 16th-31st April and 15th – 28th August, respectively. Twenty individuals were trained in each session. The courses focused on the African catfish (*Clarias gariepinus*) fingerling production process, including maintenance of broodstock, brooder selection, spawning, incubation, hatching, and rearing of fry to the fingerling stage. In addition, two on-farm training sessions were conducted for advanced farmers during 2005 and early 2006. The first fish farmers training session was held on the Chepkoilel Campus and at Kesses Division, Uasin Gishu District, next to the Moi University Main Campus from 19th to 21st May 2005. The second training was held at Chepkoilel Campus from 2nd to 5th April 2006. The training session consisted of hands-on spawning/hatching/rearing work conducted by the farmers themselves under the guidance of a host farmer and one or more experienced technicians from MU and the FD. Four MU

undergraduate students received support for their senior project work and two graduate students received full scholarship support. Both graduate students have completed their coursework and research and have submitted their theses for review by their graduate committees. Ms. Boit's thesis was sent to the Graduate School and reviewed by examiners and her defense was held on 30th May 2007. She successfully defended her thesis, made her corrections, and graduated on 19 October, 2007. Mr. Njau's thesis was reviewed by his committee, submitted to the graduate school, and sent to the external reviewers in July 2007. Based on the reviewers' comments, a date for his defense will be set.

Completion of this investigation will benefit Kenya and the region in many ways. Extension workers and fish farmers will be able to apply new knowledge to increase *Clarias* fingerling production on government and private farms. An increased supply of *Clarias* fingerlings will provide Lake Victoria Nile perch fishers with a reliable source of bait and fishing pressure on immature *Clarias* in the Lake will decrease. A steady supply of *Clarias* fingerlings will also help producers in areas where *Clarias* is gaining popularity as a cultured food fish, and farmers producing *Clarias* fingerlings will enjoy an additional source of income. Increases in fish production realized through all these avenues will contribute to human health and welfare in the region.

INTRODUCTION

Efforts to grow fish in ponds in Kenya began in early 1920. However, rural fish farming dates back to 1940s when farmers in Central and Western Kenya started to construct fish ponds to culture Nile tilapia. In spite of several decades of fish culture, Kenya's aquaculture has not come far and remains a young industry, practiced mainly on a small scale using Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) and producing only about 1,000 metric tons annually (Kenya Fisheries Department, 2000).

The African catfish, *Clarias gariepinus*, is probably the most widely distributed fish in Africa (Skelton 1993). It can endure very harsh conditions by using its accessory air breathing organ, is highly omnivorous, and grows quickly. The fish has high potential for aquaculture in this region. Research into the culture potential and the artificial propagation of catfish is reported to have begun in the 1970's. (DeKimpe and Micha 1974; Hogendoorn 1984).

Clarias gariepinus is endemic to the Lake Victoria region. It is popular with the communities living around the lake and a lot consider its taste as excellent. *Clarias* are farmed in polyculture with Nile tilapia to control unwanted reproduction. They are also grown in monoculture as food fish. More recently, *Clarias* culture has gained in importance as a way of producing bait fish for the Lake Victoria Nile perch industry. The traditional supply of bait fish is wild-caught catfish fingerlings from Lake Victoria itself, but this supply is intermittent and seems to be related to the extent of water hyacinth rafts drifting in near shore, with *Clarias* being numerous under the water hyacinth. Fishers sometimes use small-mesh beach seines and mosquito nets to catch fingerlings for bait, but beach seining is highly destructive of the spawning habitats of native cichlids and is illegal (Abila, 2000). Fishing with mosquito nets has also recently been banned by the government. Fishers find themselves in a difficult situation because they need the bait at an affordable price to be able to continue fishing.

Like many other indigenous fish species tried in aquaculture, lack of adequate seed is a constraint to *Clarias* production. Spawning is not a major problem, but sufficient quantities of fingerlings cannot be produced due to very low survival of fry to fingerling size. Spawning success as reported by Karen Veverica (Personal Communication) was quite good, but survival to fingerling size was variable, ranging from 1 to 50% in ponds, with a survival rate of 25% from egg to 5-gram fingerling considered good, illustrating that further work on increasing survival to the fingerling stage continues to be needed.

Some improvements in *Clarias* survival were realized through experiments conducted at Moi University (MU) under CRSP sponsorship in 2002 and 2003. Those experiments included studies

on suitable stocking densities, best first feeds, and the benefits of providing shading and cover for fry reared in hapas in outdoors tanks. The feeding experiment demonstrated that pond-cultured rotifers can successfully and economically be used as first feeds for *Clarias* fry, and the aquarium stocking density study suggested that the best survival and growth can be achieved when larvae are stocked at about 10 per litre. In the pond/hapa experiments, it was shown that lower stocking densities—around 100 larvae/m²—gave better survival and growth than higher stocking densities (200 and 400 fry/m²). Finally, provision of 100% shading over hapas placed in ponds resulted in better growth and survival of fry than did provision of less shade (60, 30, and 0% coverage) (Ngugi et al., 2004a, 2004c).

Previous short courses supported by the CRSP focused on basic aquaculture knowledge such as evaluating potential pond sites, constructing and managing ponds, and the economics of running fish farming enterprises (Ngugi et al., 2004b; Ngugi et al., in press). In contrast, the training courses conducted under this activity focused specifically on the production of *Clarias gariepinus* fingerlings, targeting extension workers and farmers wishing to increase the production of catfish fingerlings. In addition, support was provided to four undergraduate and two graduate aquaculture students at Moi University. The graduate students conducted research on additional factors affecting the growth and survival of *Clarias gariepinus* fry while pursuing their masters degrees (see related report on “Studies on Strategies for Increasing the Growth and Survival of African Catfish (*Clarias gariepinus*) Juveniles Reared for Stocking or for Use as Bait” for details on their work).

MATERIALS AND METHODS

The objectives of this investigation were:

- To train up to 34 extension workers and 6 advanced farmers in hatchery management techniques at government or university farms
- To provide on-farm training for up to 12 farmers in simple techniques for spawning, hatching, and rearing catfish juveniles in ponds
- To provide support for four undergraduate university students training in aquaculture
- To provide support for two university students for Master’s-level (MSc) training in aquaculture

These objectives were met by carrying out the following sets of activities.

Training of extension workers and advanced farmers

Two two-week short courses on *Clarias* propagation (fingerling production) were offered to selected FD Fisheries Assistants (extension workers), KMFRI research officers, and advanced fish farmers. The courses focused on the whole fingerling production process, from maintenance of *Clarias* broodstock through brooder selection, spawning, incubation, hatching, and rearing of fry through the first 21-28 days after hatching. Trainers for these courses were selected from among MU and FD personnel who have worked on *Clarias* production and research during the past few years.

On-farm farmer training

Farmer training was conducted at the farms of two selected leading farmers in western Kenya. The host farmers were selected from among those who had participated in the two-week training sessions described above under “Training of extension workers and advanced farmers.” The training consisted of hands-on spawning/hatching/rearing work conducted by the farmers themselves under the guidance of the host farmer and one or more experienced technicians from either MU or the FD. Trainers taught the best available techniques from published research results, local experience, and recent CRSP-sponsored experiments that are practicable under local conditions. FD and MU technicians who assisted the host farmers were selected from among those with prior *Clarias* hatchery experience, for example individuals who have been working with

Clarias at either Sagana Fish Farm or the MU Fish Farm or recent MSc graduates who worked on CRSP Clarias production experiments in 2002 and 2003.

Support for undergraduate students in aquaculture

Short-term stipends were provided to support senior project work for four selected undergraduate students studying in their final year at Moi University. The work of these students was supervised by Dr. Charles Ngugi.

Support for master's degree (MSc) aquaculture students

Two individuals were selected to receive full support (full tuition and living stipends) for two years while conducting research to improve *Clarias* seed production techniques and work towards earning masters degrees (MSc).

RESULTS

Training of extension workers and advanced farmers

The two training sessions for this activity were held at Sagana Aquaculture Center and Moi University Fish Farm, on 16th-31st April and 15th – 28th August, 2005, respectively. Twenty individuals were trained in the first session and another thirty in the second session. The training programmes and lists of names are as shown in Attachments 1-7. The thirty individuals who received training at Moi University are shown on separate lists as Attachments 5-7, one each for fisheries extension officers (Attachment 5), farm/hatchery managers from Uganda (Attachment 6), and Kenyan farmers and KMFRI technicians (Attachment 7).

On-farm farmer training

The first of these two training sessions was held at Chepkoilel Fish Farm as a farmer field day on 19th May 2005 while the second was held at the farm of Mr. Joseph K. Mbugua on 21st July 2005.

Support for undergraduate students in aquaculture

The four undergraduates who received support under this activity were Lauryn Mutai, Mary Makhutu, Ruth Muhonja, and Spencer Otieno.

Their senior thesis topics were as shown below:

1. Lauryn Chebet Mutai:

Effects of organic and inorganic fertilizers on water quality in static ponds

2. Mary Makhutu:

Determination of moisture and fat content in *Oreochromis niloticus* and *Clarias gariepinus* farmed at Chepkoilel Fish Farm, Moi University

3. Ruth Muhonja:

The significance of energy expenditure on egg production to growth in females of *Oreochromis niloticus*

4. Spencer Otieno Ogot:

Effects of zooplankton succession in fertilized ponds on growth performance and survival of African Catfish, *Clarias gariepinus* larvae

Support for master's degree (MSc) aquaculture students

The two master's degree students selected for this program were Ms. Victoria Boit and Mr. Stephen Njau. They conducted their work under the supervision of Dr. Charles Ngugi (Head, Department of Fisheries, Moi University) and Dr. James Bowman (Department of Fisheries and Wildlife, Oregon State University), with further advisory help from Mr. Bethuel Omolo (Head of Station, Sagana Fish Farm, Kenya Fisheries Department). They began their work in September 2004 and continued to receive support through December 2006. In his research, Mr. Njau looked at the influences of different hatchery (aquarium) rearing periods followed by stocking into hapas in ponds at different densities on the growth and survival of catfish larvae; his thesis title is thus "Effect of hatchery rearing duration and stocking density on growth and survival of the African catfish (*Clarias gariepinus*, Burchell, 1822) larvae reared in hapas suspended in a static pond." Ms.

Boit conducted experiments on light-dark regimes and alternative feeding regimes in a hatchery setting, and her thesis title is “Effects of Three Feeding Regimes and Two Light Regimes on Growth and Survival of African Catfish (*Clarias gariepinus*, Burchell, 1822: Family Clariidae) Larvae.” Details on their research can be found in our final report for the investigation entitled “Studies on Strategies for Increasing the Growth and Survival of African Catfish (*Clarias gariepinus*) Juveniles Reared for Stocking or for Use as Bait (11.5SDA2, Seedstock Development and Availability/Experiments). Both students have completed their coursework and research and have submitted their theses for review by their graduate committees. Ms. Boit’s thesis sent to the Graduate School was reviewed by examiners and her defense was held on 30th May 2007. She successfully defended her thesis and was given one month to make corrections and submit final bound copies of the thesis; she will be on the list of the next graduants. Mr. Njau’s thesis was reviewed by his committee, submitted to the graduate school, and sent to the external reviewers in July 2007. Based on the reviewers’ comments, a date for his defense will be set.

ANTICIPATED BENEFITS

Extension workers and fish farmers who have been trained in the latest, best techniques will now apply that knowledge to increasing the production of *Clarias* fingerlings on both government and private farms. An increased supply of *Clarias* fingerlings will provide Lake Victoria Nile perch fishers with a reliable source of bait. Fishing pressure on immature *Clarias* in Lake Victoria will be reduced. Reduction in beach seining will reduce habitat destruction on native fishes in Lake Victoria. Net income to fishermen may increase if baitfish is more available and if costs are kept down through competition among bait producers. A steady supply of *Clarias* fingerlings will also help producers in areas where *Clarias* is gaining popularity as a cultured food fish, and farmers producing *Clarias* fingerlings will enjoy an additional source of income. As with the *Clarias* fingerling production research to be conducted under this project, increases in fish production realized through all these avenues will contribute to human health and welfare in the region. On the capacity building/outreach/educational side, MU and FD course instructors gained valuable experience in the practical aspects of *Clarias* spawning and rearing as well as in methods of teaching these techniques to farmers and extension agents. The aquaculture handbook prepared as part of an earlier CRSP/Kenya project has been improved following these training courses, both with respect to its organization and the technical information it provides.

Finally, collaboration on this project has strengthened capacities in both of the primary institutions involved—the MU Fisheries Department and the Kenya Fisheries Department—and has also strengthened the linkage between them. Graduate training provided for FD personnel has further contributed to the capacity of that Department.

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ATTACHMENT 1

COURSE OUTLINE FOR TWO-WEEK EXTENSION WORKERS' TRAINING PROGRAM IN HATCHERY MANAGEMENT TECHNIQUES FOR PROPAGATION OF AFRICAN CATFISH, *CLARIAS GARIEPINUS*

DURATION: TWO WEEKS

Target group: The course is designed for Fisheries Assistants and advanced fish farmers

Requirements: Participants must have a minimum of primary school education.

MAJOR TOPICS:

1. Techniques for the management of catfish juveniles
 2. Catfish Seed and larval production
 3. Catfish Fish larval nutrition
 4. Fish health management
-
1. **Simple techniques for the management of catfish juveniles**
Water quality monitoring
Pond fertilization
Stocking density in ponds, cropping and harvesting
Sanitation practices
 2. **Seed and larva I production**
Methods of Catfish seed production
Hatchery production techniques
Broodstock collection
Spawning techniques
Fertilization
Incubation and hatching
Causes of egg mortality and their treatment
Larval rearing
Mass fry production of catfish and other fish.
Transportation of fish seed
 3. **Fish Nutrition and feed formulation**
Nutritional requirements of fish
Protein, Dietary energy, Vitamins, Minerals, Essential lipids
Feeding regimes, Feed formulation and processing
 4. **Fish health management**
Introduction to stress and the disease process
External signs of infection in fish
Types of fish diseases
Methods of disease control, Preventive husbandry
Methods of disinfection, Principles of quarantine
Mass drug therapy, Immunization with vaccines

ATTACHMENT 2.
TRAINING PROGRAMME IN HATCHERY MANAGEMENT TECHNIQUES FOR PROPAGATION OF
AFRICAN CATFISH, *CLARIAS GARIEPINUS*

For this activity two training sessions were held, the first at Sagana Aquaculture Centre on 16th-31st April, 2005, and the second at the Moi University Fish Farm, and 15th – 28th August, 2005.

Day	Activities
Week One Day 1	Registration, stationery supply & training materials Opening remarks: Principal Chepkoilel Campus and Director of Fisheries Self introduction of all training staff and trainees Explanation of training materials that will be used. Objectives of training program. Administrative questions Tour of training site fish farm and the hatchery.
Day 2	Discussion on biology of catfish Seining for <i>Clarias</i> , handling brooders, sexing and pituitary injection.
Day 3	Removal of pituitary from <i>Clarias</i> for Hypophysation, other methods of breeding catfish Stripping, fertilization & incubation of <i>Clarias</i> eggs Soil Qualities and Liming
Day 4	Preparation of ponds for fry stocking Fertilization of Ponds and Calculation of Fertilizer and Manure Application Rates
Day 5	Observation of incubated <i>Clarias</i> eggs for hatching Fieldwork estimation of <i>Clarias</i> and stocking fry in hapas Introduction to Water Quality management Monitoring catfish growth performance
Day 6	Hatchery Nursing of catfish fry Monitoring catfish growth performance
Day 7	Rest day
Week Two Day 8	Monitoring catfish growth performance Fish Feed and Nutrition (Juveniles)
Day 9	Monitoring catfish growth performance
Day 10	Monitoring catfish growth performance
Day 11	Field visiting to Fish Farmers' Farms
Day 12	Discussion on Extension Services
Day 13	Course assessment
Day 14	Presentation of Certificates and Closing

ATTACHMENT 3
COURSE OUTLINE FOR ONE-WEEK CATFISH FARMERS’ TRAINING PROGRAM

Major Topics to be covered

- Seed and Larval Management
- Spawning process both in Nature and in the hatchery
- Basic equipment used
- Selection of Spawners
- Collection of pituitary
- Fertilization and incubation of eggs
- Larval development Nursing fry growth and survival of fry
- Fish health management
- What have we learned so far!

Day	Activities
Week One Day 1	Registration, stationery supply & training materials Opening remarks Self introduction of all training staff and trainees Explanation of training materials that will be used. Objectives of training program. Administrative questions Tour of farmers site
Day 2	Discussion on biology of catfish Seining for <i>Clarias</i> , handling brooders, sexing and pituitary injection. Simple techniques in propagation of catfish
Day 3	Further discussion on breeding catfish fertilization & incubation of <i>Clarias</i> eggs Fieldwork estimation of <i>Clarias</i> fry spawned
Day 4	Soil Qualities and Liming, Preparation of ponds for fry stocking Fertilization of Ponds and Calculation of Fertilizer and Manure Application Rates
Day 5	Monitoring catfish growth and survival Discussion on constraints in catfish fry production
Day 6	How to nurse catfish fry Discussion
Day 7	Presentation of Certificates and Closing

ATTACHMENT 4

List of fisheries assistants and selected fish farmers trained in hatchery management, fry production, and pond maintenance at Sagana Aquaculture Centre, 10th – 23rd April 2005.

	Name	Designation	Station
1.	David K. Kamau	Fisheries Assistant	Nyandarua
2.	Christopher Leshingia	Fisheries Assistant	Isiolo
3.	Francis Warui Kariuki	Fisheries Assistant	Meru South
4.	Judith W. Muya	Fisheries Assistant	Nyeri
5.	Patrick Muchina	Fisheries Assistant	Nyeri
6.	Serah W. Kamanu	Fisheries Assistant	Kiambu
7.	Millicent W. Mani	Fisheries Assistant	Embu
8.	Philip M. Ndirangu	Fisheries Assistant	Muranga
9.	Obadia K. Mburu	Fisheries Assistant	Muranga
10.	Samson K. Ngigi	Snr. Fish Scout,	Taita Taveta
11.	Julius M. Mkungo	Fisheries Assistant	Taita Taveta
12.	Hezekiah N. Ondari	Fisheries Assistant	Kericho
13.	Richard O. Ochido	Fisheries Assistant	Bomet
14.	Penina N. Njenga	Fisheries Assistant	Kiambu
15.	Joseph M. Kahiga	Farmer	Nyandarua
16.	James K.E. Maina	Farmer	Embu
17.	Daniel Ndungu Kambo	Farmer	Muranga
18.	Daniel Mutai	Farmer	Kericho
19.	Dancan Kabia	Farmer	Nyeri
20.	Joseph Muchangi	Farmer	Embu

ATTACHMENT 5

List of fisheries extension officers trained in small-scale commercial fish farming at Moi University 15th – 28th August, 2005.

Name	P/NO/ID	Designation	District
1. Jashon O. Ochola	87028665	FA 11	Kisii
2. Hudson N. Murunga	1982113813	FA 1	Bungoma
3. Fred Nyambega	1982059920	SFA	Kisii
4. Florence Musieka	83076925	FA 1	Kakamega
5. Joseph Ombogo Onyancha	82000109	FA 1	Busia
6. Edward L. Maneno	1980112756	SFA	Trans-Nzoia
7. Isaiah K. Ligwilu	1981069362	SFS	Kakamega
8. Heman Muyesu Abade	1982113643	FA 1	Vihiga
9. Agenga E. Vallen	80101014	FA 1	Busia
10. Felix Tom Oketch	1981069859	FA 1	Gucha
11. John N. Omweno	83000039	FA 11	Trans-Nzoia
12. Barlinton M. Odanga	198111518	FA 11	Vihiga
13. Jackson A. Keya	1982060214	SFA	Butere
14. Wycliffe L. Ominde	1984124161	FA 11	Trans-Nzoia
15. Nicholas W. Oundo	11279789	Fish farmer	Busia
16. Daniel A. Otwoma	4174092	Fish farmer	Vihiga
17. David Olubwayo Angoma	9080283	Fish farmer	Butere/Mumias
18. Charles Otunga	8345033	Fish farmer	Trans-Nzoia
19. Joyce N. Nyagaka	2184798174	Fish farmer	Kisii Central

ATTACHMENT 6

List of hatchery owners/ managers from Uganda trained in small-scale commercial fish farming at Moi University 15th – 28th August, 2005.

Name	Fish Farm Name	District
1. Komakech Simon Peter	Tochi Aqua Harvest Limited	Gulu
2. Bayole Stanley	Banga Farm	Mayuge
3. Nakyewa Pauline	Ssenya Fish Farms	Masaka
4. Mugumya Collins	Tukundane Fish Farm	Mbarara
5. Samanya Musa S.	Jaff Fish Farm	Wakiso
6. Mpabukire Pauson Joshua	Sibco Fish Farm	Luwero

ATTACHMENT 7

List of fish farmers and technicians from Kenya Marine and Fisheries Research Institute (KMFRRI) trained in small-scale commercial fish farming at Moi University 15th – 28th August, 2005.

Name	P/NO/ID	STATION	DESIGNATION
1. Peter Miruka	01605	Kisumu	Lab technician IV
2. Alice B. Osinde	1591	Kisii Central	Lab technician IV
3. Lawi E. Goga	1115	Nyando	Lab technician IV
4. Samwel O. Omenya	6039551	Kisii Central	Fish farmer
5. Gerald O. Nyamwange	10021908	Gucha	Fish farmer

ESTABLISHMENT OF THE CENTER FOR AQUACULTURE TECHNOLOGY TRANSFER

Twelfth Work Plan, Applied Technology & Extension Methods 5 (12ATE5)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

A Center for Aquaculture Technology Transfer (CETRA) was created in Mexico. CETRA headquarters were housed at the University of Tabasco. Members of CETRA consisted of aquaculture professionals from the university, government, and private sectors. CETRA's goals are to support and guide aquaculture commercial enterprise development in an environmentally sustainable fashion. CETRA has established a network of academic and economic resources in Mexico and the United States that can provide extension services for meeting Mexico's sustainable aquaculture development goals. CETRA builds or will build upon past, present and future research, extension and outreach efforts made by the CRSP/USAID programs and all other pertinent efforts. CETRA members are now effectively networked through the CETRA website and by an annual meeting structure to revisit CETRA structure and elect new members to the CETRA Board of Directors.

INTRODUCTION

Nearly 40% of the seafood needed to feed the world's growing population (estimated demand of 150 million tons by 2010) is expected to come from aquaculture expansion (FAO 2004). Aquaculture growth over the past 30 years has encountered several economic, environmental, and biological constraints such as price fluctuations, mangrove destruction and viral and bacterial challenges that have led to the need for sustainable aquaculture planning and information exchange to reduce these risk factors and mitigate the pressure for more fish without concern for the environment. The USAID has expressed a need for US cooperation in sustainable aquaculture development around the world and recently indicated that,

“The sustainable development and management of aquaculture and fisheries systems can only occur if these activities are well planned and integrated into the natural and social resource, ecosystems, and farming systems of the large global context of which they are a part.” (USAID)

Dissemination of technical information as part of extension outreach to producers is thus a critical aspect of sustainable aquaculture development. Establishing an effective large-scale extension service for a developing and multi-disciplined industry is a considerable task when there are many different economic, environmental, and technical considerations needed for project success for a variety of stakeholders. Relevant research in sustainable aquaculture is being conducted within Mexico and the US today; however improved communication and extension between researchers, educators, extension agents and aquaculture producers are still needed for increased implementation and adaptation of sustainable technology.

Initial efforts to expand and strengthen extension outreach services in Mexico have recently been initiated. A consortium of US and Mexican universities along the Gulf of Mexico met in the summer of 2004 to discuss some of the research and extension challenges facing the industry. Out of this meeting, several Mexican university researcher/extension personnel were identified as extension collaborators and a listserv and website were created to support their effort. In addition to this effort, a considerable portion of current CRSP/USAID research projects in Mexico, such as

the Santa Maria Bay Management Project and collaborative tilapia research in Tabasco, have included extension workshops and outreach as part of their plans (CRSP 11th Work plan).

OBJECTIVE

The major objective of this project was to establish a center for aquaculture technology transfer that is *narrowly focused* in its scope. We called this the Center for Aquaculture Technology Transfer (CETRA) and was patterned after the U.S. SeaGrant Program model. The U.S. SeaGrant Program, which is administered through the National Oceanic and Atmospheric Administration (NOAA), is a nationwide network of 30 university-based programs that work with coastal communities (NOAA SeaGrant). The National Sea Grant College Program engages this network of the nation's top universities in conducting scientific research, education, training, and extension projects designed to foster science-based decisions about the use and conservation of aquatic resources. The U.S. SeaGrant program is focused on eleven themes and three national priority areas. The themes of interest and study under SeaGrant include aquaculture, biotechnology, coastal communities & economies, ecosystems & habitats, fisheries, and aquatic invasive species to name a few.

METHODS AND MATERIALS

Our approach was to use the Sea Grant model to establish the CETRA. We narrowed the focus of CETRA to one central theme: sustainable aquaculture development. We felt that concentration on a single theme, though broad in scope, would streamline the center's effort and increase its effectiveness. As CETRA matures, its extension services can be expanded to include additional themes that are important to the country and region. By creating a new center for aquaculture outreach (CETRA), this project attempted to expand upon efforts such as the Santa Maria Bay Management Project and collaborative tilapia research in Tabasco that also included extension workshops and outreach as part of their plans (CRSP 11th Work plan).

The CETRA was formed using a virtual network of aquaculture research and extension universities and institutions that are united through a single mission, a central website, and a director. The cooperators on CETRA are listed in the Acknowledgments section. The overall mission of the CETRA was to enhance the implementation and adaptation of sustainable aquaculture technology and information from research, economic, and regulatory sources to aquaculture production stakeholders. The CETRA also served as a uniting entity among members to steer/guide research priorities and possibly even disseminate research funding in the future. CETRA was formed in an organizational meeting at which an operating agreement was formed by the participants. CETRA funding was used to partially support an elected Director and additional funds were used to provide infrastructure support (e.g., internet service, web listing, telephone, and office materials).

Activity Plan 1: Identify and recruit potential members of the CETRA network

Correspondence using existing networks within SeaGrant was used to identify potential members of CETRA. Although the bulk of this group identified was university based, contacts were also made within the government and industry groups and they also became key contributors towards the development of the CETRA.

Two Mexican scientists were identified as potential Directors of CETRA: Dr. Perez-Sanchez and Dr. Cervantes Trujano. At the first organizational meeting of CETRA, Dr. Perez-Sanchez was elected Director. CETRA activities are anticipated to be 30% of the director's time, which were paid for (see Budget) through this project. U.S. and existing host country co-principal investigators will provide assistance to the CETRA director. All of the U.S co-principal investigators were helpful in ensuring that CETRA got off to a strong start from an organizational perspective.

A further goal of this project (CETRA) was to establish strong ties with US resources using the existing SeaGrant structure as an effective means to accomplish this. The purpose was to strengthen the extension capability of the CETRA program and to provide a basis for follow-on funding efforts. The initial relationship established by CETRA emphasized research identification and information exchange. Seeking additional funding to support these identified needs was a key goal also.

CONCLUSIONS

Effective interaction between Mexican and US scientists can be achieved by creating an umbrella organization (CETRA) to serve as the unifying force. Success as demonstrated by CETRA outcomes was achievable with modest funding. Sustained support to maintain CETRA functionality is difficult to identify. CETRA hopes that its inclusion of the private sector within its core membership will help it to secure funding in the future.

ANTICIPATED BENEFITS

CETRA has created a network of professionals for outreach that is based upon the SeaGrant model. We expect the availability of information on a broader base to individuals and small personal enterprise will accelerate the successful adaptation of new technologies that will lead to economic development for the country. Implementation and adaptation of the CETRA program will also continue to develop the channels of communication between different resources in the US and Mexico for aquaculture development and will set the stage for future cooperative research and extension activities between nations.

ACKNOWLEDGMENTS

CETRA was created by the strong support and involvement of many people. The U.S. cooperators that assisted in this project included:

- Mr. Dale Baker of Cornell New York SeaGrant;
- Dr. Michael Timmons of Cornell University,
- Mr. David Belcher of Cornell University,
- Dr. Martin Schreiber of Brooklyn College,
- Dr. John Jacob of Texas SeaGrant,
- Dr. Barry Costa-Pierce of URI/SeaGrant,
- Dr. Kevin Fitzsimmons of University of Arizona, and
- Mr. Ralph Rayburn of Texas SeaGrant.

Mr. Dale Baker who served as Principal Investigator for this project is the assistant director and lead of the New York SeaGrant Extension Program and has been involved in Cornell Cooperative Extension for over 15 years. Dr. Timmons is an internationally recognized expert in recirculating aquaculture system production and has over 20 years experience in both research and extension support through the Cornell Cooperative Extension. Mr. David Belcher is an extension associate at Cornell with over six years of commercial aquaculture experience. Dr. Martin Schreiber is the founder and director of the Aquatic Research and Environmental Assessment Center at Brooklyn College and has current collaborative research experience in Mexico. Mr. Ralph Rayburn is currently serving as assistant director of Texas SeaGrant and was recently appointed Commissioner of Gulf State Marine Fisheries Commission. Dr. John Jacob of Texas SeaGrant has a working relationship with a number of Mexican universities and was a leading member of the 2004 US/Mexico university extension meeting in Veracruz. Dr. Costa-Pierce, a collaborator in the existing CRSP.

We were also fortunate to have the input and participation of Dr. Martin Hevia (La Fundacion Chile). The successful model of Fundacion Chile was used to refine the objectives and operating

procedures of CETRA. Fundacion Chile is solely geared towards creating new commercial enterprise.

The HC co-principal investigators were Dr. Margarita Cervantes Trujano of the Instituto Tecnológico del Mar located in Boca del Rio, Veracruz and Dr. Eunice Perez-Sanchez of the Universidad Juarez Autonoma de Tabasco. Collectively, Dr Cervantes Trujano and Dr. Perez-Sanchez have extensive university contacts throughout Mexico and were instrumental in the success of this project.

KENYA TRAINING OF TRAINERS AND REGIONALIZATION OF AQUACULTURE TRAINING ACTIVITIES

Twelfth Work Plan, Applied Technology & Extension Methods 11 (12ATE11)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

This activity addressed supplemental training objectives for the OSU/Kenya project, including conducting a “training-of-trainers” (TOT) course for Fisheries Officers and two pond construction and management courses for Fisheries Assistants, taught by the newly trained trainers. In addition, support for the participation of Kenyan PI Charles Ngugi in training courses held in other countries in the region was provided.

The intent of the TOT course was to increase the number of individuals who can effectively teach basic pond construction and management techniques to extension agents and farmers in Kenya. Ten Fisheries Officers were selected for training. This highly-successful course was held at Sagana Aquaculture Centre, Sagana, Kenya, between November 20 and December 1, 2006.

The Sagana TOT course was followed by two two-week courses taught by the newly trained trainers under supervision by Dr. Ngugi. These courses occurred at Moi University Chepkoilel Campus, between January 22nd and February 2nd, 2007 and at Sagana Aquaculture centre, from 16th to 27th April, 2007. A total of 30 individuals received training during these two courses.

Regionalization of our training efforts was achieved through assistance provided to the CRSP project in Tanzania by Dr. Charles Ngugi, who provided experience, training materials, and general support for a farmers training course at Sokoine University of Agriculture in Morogoro, held from 18th to 22nd June 2007. Twenty-five farmers and several district fisheries professionals participated in this course. Dr. Ngugi drew on the experience of the over 19 short courses held between 1999 and 2007 in Kenya, along with teaching modules and a new training manual developed for those courses, to assist with preparations for and the conduct of their farmers training course. CRSP student James Mugo Bundi also participated in this effort.

OBJECTIVES

The objectives of this investigation were:

- To teach Kenyan Fisheries Officers (FOs) how to conduct pond construction and management courses for extension workers and farmers in Kenya (“training trainers”);
- To supervise newly trained FOs in conducting two additional pond construction and management courses for Fisheries Assistants (FAs);
- To promote regional collaboration on training activities and to strengthen short courses planned for other countries in the region by supporting the participation of Kenyan PI Charles Ngugi in those training sessions. Specific goals of these training sessions will include:
 - Providing training on pond management, fish feed, and fish health management,
 - Teaching the principles and benefits of record keeping, and

- Teaching simple methods for assessing and evaluating costs and benefits

INTRODUCTION

Training programs for farmers and extension agents have typically been developed and carried out independently in the several African countries in which the ACRSP has been involved. Following the cessation of activities in Rwanda in 1994, the bulk of CRSP-sponsored training done in Africa has occurred in Kenya, where well over a dozen two- and three-week training courses have been conducted and where considerable effort has been put into the development of training materials, including PowerPoint teaching modules and a Fish Farming Handbook (Ngugi et al. 2001, 2004, 2005a, 2005b; Omolo et al. 2005). More recently, the University of Arkansas at Pine Bluff and its collaborating African institutions have also planned farmer training programs to be held in neighboring Tanzania, in Ghana, and in Kenya.

In this supplemental Twelfth Work Plan investigation we addressed several new objectives for the OSU/Kenya project, including conducting additional training courses (a short course to train trainers, followed by two additional courses taught by the new trainers) in Kenya and providing support for the participation of Kenyan PI Charles Ngugi in training courses held in other countries in the region.

The intent of training trainers in Kenya was to increase the number of individuals who can effectively teach pond construction and management techniques to extension agents and farmers. As part of that effort the newly trained trainers were given two opportunities to train Fisheries Assistants under the guidance of the TOT trainers, mainly Dr. Charles Ngugi.

This investigation also provided for the participation of Charles Ngugi in training courses outside of Kenya to make the experiences and materials developed by the Kenya Project available for training efforts in the Region as a whole. Through his work with the ACRSP in Kenya, Ngugi has gained a great deal of experience in conducting this type of training course. He has concurrently developed a number of teaching modules (PowerPoint) on many of the topics typically taught in such courses. He is particularly skilled in the practical aspects of pond construction, pond and hatchery management, and in effectively teaching these to farmers and extension workers. His teaching style makes the material he presents highly accessible to the trainees. He is fluent in both of the major international languages of East Africa, Swahili and English, making it relatively easy for him to contribute in training courses in other East African countries.

MATERIALS AND METHODS

Training of Kenyan Trainers

A two-week TOT course was held at Sagana Aquaculture Centre, Sagana, Kenya, from 20 November to 1 December, 2006. Ten Fisheries Officers were selected for the training. The approach taken was to use the draft of the Project's "New Guide to Fish Farming in Kenya" as the text for the course and to have teams of two trainees each prepare teaching sessions on the topics covered in selected chapters of this guide. This training course was planned to also provide opportunities for evaluation and feedback on the fish farming guide being written so that final corrections and improvements could be made before publication. Drs. Charles Ngugi (Moi University) and James Bowman (Oregon State University) were responsible for the organization and running of this course.

Following the TOT course two additional training courses were scheduled to give the newly trained Officers opportunities to teach real courses to Fisheries Assistants (responsible for aquaculture extension activities in Kenya) under the guidance of their original instructors. These courses were scheduled and conducted at Moi University Chepkoilel Campus, from January 22nd to February 2nd, 2007 and at Sagana Aquaculture Centre, from 16th to 27th April, 2007. A total of 30 individuals received training during these two courses. Dr. Ngugi provided guidance for these two sessions.

Farmers Training in Tanzania

The Kenya Project team maintained communications with the CRSP/Tanzania team for a number of months to select a time when a coordinated farmer training course could be offered in Tanzania. After some initial scheduling difficulties a five-day course was set for 18-22 June, 2007. Mr. Kajitanus Owuory, of Aquaculture Development Division, Tanzania, based at Morogoro, was primarily responsible for the organization of this course. Dr. Charles Ngugi of the Kenya Project, along with our Kenya Project student James Mugo Bundi, traveled to Tanzania (Sokoine University of Agriculture, Morogoro) to help plan and conduct this training session. Although the primary objective of this activity as described was to train farmers, the resource persons from Kenya also spent time to discuss management strategies that might contribute to improved growth and survival of African catfish juveniles. Further, they carried out successful trials on propagation of the African catfish prior to doing a demonstration for fish farmers. Over 7 members of staff from Kingorwila Fish Farm, Morogoro, participated in this exercise.

RESULTS

Training of Trainers in Kenya

Ten officers were trained in the "TOT" workshop, which was held at Sagana Aquaculture Centre (Sagana, Kenya) from November 20 through 1 December, 2006. Trainees were selected jointly by the Director of Fisheries and the Head of the Moi University Department of Fisheries and Aquatic Sciences. Selection was based on criteria such as the potential for fish farming in each officer's area of assignment, the officer's prior performance in aquaculture extension activities in their assigned area, their apparent understanding of aquaculture (as demonstrated in previously-attended short courses or in their subsequent field work), and their ability and desire to participate in training and education (extension, outreach) activities. The draft of the first edition of the Kenya Project's new fish farming handbook, "A New Guide to Fish Farming in Kenya," was used as the "text" for the course. Topics included in the handbook are similar to those previously covered in the Project's training sessions, including evaluation of suitable sites for ponds, proper construction of ponds, appropriate management practices for completed ponds, record keeping, and the basics of farming economics. Resource persons involved in the TOT course included Charles Ngugi, Victoria Boit, Leah Cherop, James Mugo, William Kinyua, and James Bowman. Victoria Boit, Leah Cherop, and James Mugo were all either current or former students supported by the CRSP.

The officers formed five two-person teams, choosing sections of our draft of "A New Guide for Fish Farming," to use as the basis for preparing their own PowerPoint teaching modules and a teaching session on their chosen topic. Existing training modules developed by the Kenya Project team for previous training courses were made available for reference. Each team then made a PowerPoint teaching presentation, which was followed by discussion and critique sessions covering the teaching presentation and the relevant section of the teaching manual. Discussions of the presentations covered content, accuracy of the information provided, and the quality of PowerPoint modules developed. Similar topics were covered in discussion of the training manual. Many positive suggestions for improvement of the manual were made, and on return to the US Jim Bowman worked with CRSP PMO personnel to make many of the recommended changes. Overall the trainers were impressed by the understanding of pond construction and management shown by the participants, as well as by their interest in and dedication to the development of aquaculture and aquaculture programs in Kenya. The program for this course and a list of participants are contained in Attachments I and II. Field visits were also included in the program for this two-week course, including visits to Kiganjo Trout Hatchery (Trout), Mr. William Kiama's fish farm (Ornamentals) and the Murang'a Fisheries Hatchery (catfish and tilapia).

Following the TOT session the new trainees conducted two two-week short courses for FAs. Course content was similar to that of previous two-week short courses offered to FAs by the CRSP. The first course was held at Moi University, Chepkoilel Campus (Eldoret) between January 22nd and February 2nd, 2007. Fifteen extensionists were trained (14 male, 1 female). The second of

these courses was held at Sagana Aquaculture Centre from 16th to 27th April, 2007. In the second course another fifteen extensionists were trained; however in this case there were 7 females and 8 males in the group. During these two courses, guidance for the new trainers was provided by Charles Ngugi. Additional people who served as resource persons included former and present CRSP students. The programs, lists of trainees, and names of resource persons for these two courses are shown in Attachments III-IX.

Farmers Training in Tanzania

The five-day training workshop for farmers, sponsored by the CRSP/Tanzania Project, was conducted from 18 to 22 June, 2007. Mr. Kajitanus Owuory, of Aquaculture Development Division, Tanzania, based at Morogoro, was primarily responsible for the organization of this course. From the Kenya Project, Dr. Charles Ngugi and CRSP student James Mugo Bundi traveled to Tanzania to help plan and conduct the session. The course took place at Sokoine University of Agriculture in Morogoro. Major topics covered included pond construction and management, propagation of African catfish and tilapia, fish health, fish nutrition, and fish economics. Instruction was provided by three persons from Sokoine University of Agriculture (SUA), two persons from Kingorwila National Fish Center (KNFC), two persons from MFC, one person from UAPB, along with Dr. Ngugi and Mr. Mugo. Twenty-five fish farmers from different participating villages in the Morogoro region were trained, along with several district fisheries professionals, with a focus on the training of women and household members who typically manage fish ponds. The full report on this training course will be submitted by the CRSP Purdue/Tanzania Project.

DISCUSSION AND CONCLUSIONS

The TOT course was an excellent way to wrap-up the long series of training sessions the Kenya Project team carried out over the ten years of the Project and a fitting way to ensure that a larger number of individuals are now capable and prepared to meet future training needs in the country. We were impressed by the capabilities of the group of Fisheries Officers who participated in this course, and are confident in their ability to train farmers and other members of the Fisheries Department in the skills required for building ponds and then managing them. We also appreciated the constructive feedback they provided with regard to training modules and our "New Guide to Fish Farming in Kenya," which we have put so much effort into developing.

The farmer training course in Tanzania provided us with an opportunity to increase and extend the benefits of our work as well as strengthen ties with another country in East Africa. We had an opportunity to meet and share thoughts with senior staff in the Tanzania Fisheries Division, including the Director of Fisheries, and to foster collaboration with staff teaching fisheries and aquaculture at Sokoine University of Agriculture. We exchanged ideas on breeding and management strategies for catfish, especially in the areas of starter feeds and survival to the fingerling stage.

ANTICIPATED BENEFITS

Ten Fisheries Officers were trained to train other extension workers (Fisheries Assistants) and farmers in appropriate methods for pond construction and management. These officers subsequently trained thirty Fisheries Assistants (extension officers), who will now be able to disseminate construction and management information to farmers operating new and existing fish ponds, leading to increased production of both fingerlings and food fish on their farms. In Tanzania, 25 farmers and several district fisheries professionals received training in pond construction, pond management, and pond record keeping, and they should now also be able to increase production in their ponds and farms.

On the outreach and education side, course instructors in other parts of the region benefited from Dr. Charles Ngugi's experience in methods for teaching pond construction and management

techniques to farmers and extension agents. One graduate student (James Mugo Bundi) benefited profoundly through this travel and exposure. Training modules and the fish farming handbook drafted by members of the CRSP/Kenya project were made available for use and the development team received very useful feedback from course participants, enabling us to make important modifications and improvements to both (modules and manual), with respect both to organization and content, prior to finalization.

Finally, collaboration on training efforts has strengthened the training capacities of all of the institutions involved, including those of the collaborating institutions in Tanzania (Sokoine University of Agriculture and the Tanzania Fisheries and Aquaculture Development Division) and those of the Moi University Department of Fisheries and Aquatic Sciences (Eldoret, Kenya) and the Kenya Fisheries Department.

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ATTACHMENT I
PROGRAM FOR THE TRAINING OF TRAINERS (TOT) COURSE, 20 NOVEMBER – 1 DECEMBER,
2006

WEEK 1

Day 1	Monday	Registration of Participants Speeches by Head of Station, Head (Fisheries Moi University), Dr. Bowman ACRSP, ADF Eastern & Central, Director of Fisheries Lunch Ngugi and Cherop: Introduction of course and an overview of the programme Tour of Sagana Farm Group formation and Discussion
Day 2	Tuesday	Introduction to course modules and Fish farm manual Lunch Group assignments Chapter one of the manual and the related module presentations
Day 3	Wednesday	Chapter two of the manual and the related module presentations Lunch Chapter two of the manual and the related module presentations
Day 4	Thursday	Chapter three of the manual and the related module presentations Lunch Chapter three of the manual and the related module presentations Group discussion
Day 5	Friday	Chapter four of the manual and the related module presentations Lunch Chapter four of the manual and the related module presentations
Day 6	Saturday	Group Discussion – Reviewing the modules and the manual
Day 7	Sunday	Rest day

WEEK 2

Day 8	Monday	Field trip to Kiganjo trout Hatchery (Trout)
Day 9	Tuesday	Chapter five of the manual and the related module presentations Lunch Field Trip to Kiama's fish farm (Ornamentals)
Day 10	Wednesday	Chapter five of the manual and the related module presentations Lunch Chapter six of the manual and the related module presentations Group discussion
Day 11	Thursday	Chapter six of the manual and the related module presentations Lunch Murang'a Fisheries Hatchery (catfish and tilapia)
Day 12	Friday	Manual Review and assessment FAQs
Day 13	Saturday	Trainees leave

ATTACHMENT II

List of participants in the Training of Trainers (TOT) course, 20 November – 1 December, 2006. All trainees were males.

Name	Address	Office phone	Cell phone	Email
Mbugua	58187 Nairobi 00200	3742320/49	0722357980	mmkarango@yahoo.co.uk
Mwangi				
Edwin Muga	700 Kisii 40200	05830070	0733448048	otmuga@yahoo.com
John Otiego	3948 Eldoret 30100	0532030567	0722269127	j.otiego@yahoo.com
Sammy	1084 Kisumu		0724681954	sammacharia@yahoo.co.uk
Macharia				
Patrick Mbaabu	3218 Meru		0721339035	Mbaapatri@yahoo.com
Felix Lagat	12592 Nyeri		0722606574	felixlagat@yahoo.com
Julius Nzeve	147 Muranga 10200	06030262	0722243832	jnzeve@yahoo.com
Roy Aseka	586 Kakamega 50100	05630463	0722832432	royaseka@yahoo.com
Paddy Odary	2169 Kitale	05431028	0722222837	odarindonga@yahoo.com
Henry Nzinga	142 Busia	05522168	0734774155	Henmwabari@yahoo.com

ATTACHMENT III

Program for the first training course in *Pond Management for Commercial Fish Farming* taught by the newly trained trainers. This course was held at Moi University, Chepkoilel Campus, from 21 January – 3 February, 2007.

Day 1 (Sunday 21st January 2007)

04.00pm – 06.00pm Arrival and registration of trainees - Kinyua/Mugo

Day 2 (Monday 22nd January 2007)

9.30.00 – 10.00: Opening remarks; self introduction of all training staff and trainees

Cherop

10.00 - 10.30: Tea break

10.30 - 01.00: Tour of Chepkoilel Fish Farm Hatchery – Nzeve/ Mugo/ Cherop

01.00 - 02.00: Lunch

02.00 – 05.00 Tour of Chepkoilel Fish Farm- Mugo/ Nzeve/ Kinyua/ Cherop

Day 3 (Tuesday 23rd January 2007)

10.00 – 10.30:	Official opening ceremony <ul style="list-style-type: none"> • Welcome and introduction of trainees • Remarks on the training by Head of Fisheries & Aquatic Sciences, Dr. Charles C. Ngugi • Welcome address by the Dean, School of Natural Resource Management • Opening the Training by Director of Fisheries – Mr. B. Ayugu
01.00 – 02.00:	Lunch
02.00 – 02.30:	Objectives of the training and introduction to the course – C. Ngugi
02.30 – 03.30	Commercial small scale fish farming in Africa - C. Ngugi
03.30 – 04.00	Tea break
04.00 – 05.00	Catfish Seed production – Nzeve

Day 4 (Wednesday 24th January, 2007)

08.00 –10.00:	Site selection, pond design and construction	- Nzeve/Mbugua
10.00 – 10.30:	Tea Break	
10.30 – 11.30:	Aquaculture production systems - Mbugua	
11.30 – 01.00	Intensification and Integration fish into your farm - Mbugua	
01.00 – 02.00:	Lunch	
02.00 – 04.00:	Fieldwork on fish seining, handling brooders, Sexing and propagation of Catfish and goldfish - Nzeve/Mugo/Wambui	
04.00- 05.00	Fieldwork – Removal of pituitary, injection, putting induced fish in hapas & tanks, – Nzeve/Mugo/Wambui	

Day 5 (Thursday 25th January, 2007)

08.00 – 09.00:	Stripping/ Fertilization/ Incubation of eggs and removing of brooders (field work) – Nzeve/Mugo/ Wambui
09.00 – 10.00:	Suitable fish species for culture in Kenya / Polyculture – Cherop/Otiego
10.00 – 10.30:	Tea Break
10.30 – 12.00:	Trout culture – C. Ngugi /Otiego
12.00 – 01.00	Ornamental fish culture - Mugo
01.00- 02.00:	Lunch
2.00 – 05.00:	Pond management <ul style="list-style-type: none"> Pond preparation/stocking – Otiego/ Cherop Fish feeding – Otiego/ Cherop Water quality and management – Cherop/Otiego Fish harvesting and post harvesting handling – Otiego/Mbugua

Day 6 (Friday 26th January, 2007)

08.00 – 09.00:	Observation of fertilized eggs (Catfish and goldfish) – Nzeve/Mugo
	Pond management <ul style="list-style-type: none"> Disease/ predator/ weeds control – Nzeve/Otiego
09.00 – 10.00:	Aquaculture record keeping – Mbugua
10.00 – 10.30:	Tea Break
10.30 – 01.00:	Fish farming economics – Mbugua/Njuguna <ul style="list-style-type: none"> Market analysis Enterprise budgeting
01.00 – 02.00	Lunch
02.00 – 03.00:	Egg mortality/ Fry rearing/ Nursery preparation – Nzeve/Mugo
03.00 – 05.00:	Enterprise budgeting Cont– Mbugua/Njuguna
05.00 – 06.00:	Monitoring catfish hatching performance - Nzeve/Mugo/Wambui

Day 7 (Saturday 27th January, 2007)

08.30 – 10.00: Principals of hatchery management –C. Ngugi/Nzeve
 10.00 – 10.30: Tea break
 10.30 – 01.00: Hatchery management cont – C. Ngugi/Nzeve
 01.00 – 02.00: Lunch
 Free afternoon/ Visit Hatchery

Day 8 (Sunday 28th January, 2007)

Rest

Day 9 (Monday 29th January, 2007)

08.00 – 09.00: Accounting in aquaculture - Njuguna
 09.00 – 10.00: Fish nutrition– Cherop/Otiego
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Cash flow analysis – Mbugua/Boit
 01.00 – 02.00: Lunch
 02.00 - 04.00: Exercises on cash flow development- Mbugua /Njuguna
 04.00 – 05.00: Field work on nursery pond preparations Nzeve/Cherop

Day 10 (Tuesday 30th January, 2007)

Field trip (Visit to small scale fish farmers) Kinyua

Day 11 (Wednesday 31st January, 2007)

08.00 – 09.00: Feed formulation and processing – Cherop/Otiego
 09.00 – 10.00: Tilapia seed production C. Ngugi / Cherop
 10.30 – 10.30: Tea
 10.30 – 11.30: Fish transportation – Nzeve/Mugo
 02.00 – 04.00: Monitoring Enterprise performance – Mbugua/Boit
 04.00 – 05.00: Extension services delivery Mbugua

Day 12 (Thursday 1st February, 2007)

08.30 – 10.00: Investment and risk analysis - Mbugua/Boit
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Fish marketing and emerging markets – Njuguna/Mbugua
 01.00 – 02.00: Lunch
 02.00 – 04.00: Fish processing and cooking – Cherop/Boit

Day 13 (Friday 2nd February, 2007)

08.30 – 10.00: Fish transportation and stocking catfish fry - Mugo
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Course evaluation - Amadiva
 01.00- 02.00: Lunch
 03.00 - 05.00: Closing ceremony – Principal, Chepkoilel Campus
 Dean, School of Natural Resource Management.

Day 14 (Saturday 3rd February, 2007)

Trainees leave

ATTACHMENT IV

List of participants in the first training course in *Pond Management for Commercial Fish Farming* taught by the newly trained trainers. This course was held at Moi University, Chepkoilel Campus, from 21 January – 3 February, 2007.

Number	Name	Gender	District
1	Lawrence Mireri	M	Gucha
2	Peter Bosire	M	Gucha
3	Abednego Mobegi	M	Nyamira
4	Jackson Keah	M	Kakamega
5	Wilson Upalo	M	Kakamega
6	Wycliff Ominde	M	Trans-Nzoia
7	Evans Machuka	M	Uasin Gishu
8	Enock Ashilaka	M	Busia
9	Edwin Cheloti	M	Bungoma
10	John Omweno	M	Trans-Nzoia
11	Jackon Ocholla	M	Kisii
12	Elishama Njeli	M	Vihiga
13	Gilbert Lago	M	Vihiga
14	Jamlick Njeru	M	Trans Nzoia
15	Veronica Wilson	F	Uasin Gishu

ATTACHMENT V

Trainers and resource persons involved in the first training course in *Pond Management for Commercial Fish Farming*, taught at Moi University, Chepkoilel Campus, from 21 January – 3 February, 2007.

NAME	GENDER	ID or P/NO.	Station
1. Henry M. Mbugua	M	93000104	Fisheries HQ Nairobi
2. John O. Otiego	M	89127619	Uasin Gishu
3. Julius Kioko Nzeve	M	97041071	Murang'a
4. Sarah Njuguna	F	Finance	Moi University
5. Victoria Boit	F	Grad Student	Moi University
6. Leah Cherop	F	Grad Student	Moi University
7. Charles C. Ngugi	M	02347	Moi University
8. James Mugo Bundi	M	Grad Student	Moi University
9. William Kinyua	M	Snr Technician	Moi University
10. Beatrice Wambui	F	Hatchery Attendant	Moi University

ATTACHMENT VI

General program for the second training course in *Pond Management for Commercial Fish Farming* taught by the newly trained trainers. This course was held at Sagana Aquaculture Center from 16 - 26 April, 2007.

Day 1 (Monday 16th April, 2007)

10.00 – 01:00

- Official opening ceremony
- Welcome and introduction of trainees
- Remarks on the training by Head of Fisheries & Aquatic Sciences, Dr. Charles C. Ngugi
- Opening the Training by Director of Fisheries – Mr. B. Ayugu

01.00 – 02.00: Lunch

02.00 – 02:30 Objectives of the training and introduction to the course - Charles C. Ngugi

02:30 – 04:00 Commercial small scale fish farming in Africa – Charles C. Ngugi

04.00 – 05.00 Cat fish seed production - Lagat

05: 00 – 05:30 Practical on cat fish propagation - Lagat /Mugo/ Ireng

Day 2 (Tuesday 17th April, 2007)

08.30 – 10.00: Stripping/Fertilization/Incubation of eggs (field work) –

Lagat/Mugo/Ireng/Kinyua

10.00 – 10.30: Tea Break

10.30 – 11.30 Ornamental fish culture - Mugo

11.30 – 01.30: Field work on sexing and propagation of goldfish & egg collection from mouth brooding tilapia– Mugo/ Kinyua/ Ireng

12.30 – 01.30: Lunch

01.30 – 03.30: Site selection, pond design and construction – Lagat/Boit

03.30- 05.00 Suitable fish species for culture in Kenya / Polyculture of tilapia and catfish– Otiego /Boit

Day 3 (Wednesday 18th April, 2007)

08.00 – 09.00: Harvesting and incubation of goldfish eggs– Lagat /Mugo/ Kinyua / Ireng

09.00 – 10.00: Aquaculture record keeping – Macharia

10.00 – 10.30: Tea Break

10.30 – 1.00: Pond Management

–Pond preparation / Stocking - Boit

- Fish feeding- Otiego

- Water quality- Lagat

- Fish harvesting and post-harvest handling - Otiego

01.00- 02.00: Lunch

2.00 – 03.00: Transportation of fish seeds - Lagat /Mugo

03.00 – 05.00: Field work on nursery pond preparation - Boit/ Mugo/ Kinyua / Ireng

05.00 – 06.00 Observation of fertilized eggs (Catfish and goldfish) – Lagat / Mugo/ Kinyua / Ireng

Day 4 (Thursday 19th April, 2007)

08.00 – 10.00: Pond Management

– Disease, Predator, Weeds control - Otiego/ Lagat

10.00 – 10.30: Tea Break

10.30 – 01.00: Trout culture – Dr. Ngugi / Otiego

01.00 – 02.00: Lunch

02.00 – 04.00: Fish Farming Economics - Market Analysis / Fish enterprise budgeting – Macharia

04.00 – 05.00: Fry rearing techniques – Boit /Mugo

05.00 – 06.00: Monitoring catfish growth performance - Lagat /Mugo/ Kinyua / Ireng

Day 6 (Friday 20th April, 2007)

Field trip - All resource persons.

Day 7 (Saturday 21st April, 2007)

08.00 – 10.00: Cash flow analysis and class exercises – Macharia / Boit
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Principles of Fish Hatchery Management – Dr. Charles C. Ngugi / Lagat
 01.00 – 02.00: Lunch
 02.00 - 4.00: Tilapia seed production – Dr. Charles C. Ngugi
 04.00 – 06.00: Fish nutrition – Mugo/Boit

Day 7 (Sunday 22nd April, 2007)

Rest

Day 8 (Monday 23rd April, 2007)

08.00 – 09.00: Feed formulation and processing – Mugo/Boit
 09:00 – 10:00: Investment and Risks Analysis - Macharia / Boit
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Catfish survival and stocking densities– Dr. Ngugi/Lagat
 01.00 – 02.00: Lunch
 02.00 – 04.00: Extension Services Delivery – Otiego
 04.00 – 05.00: Sampling/monitoring of catfish performance – Boit / Mugo/ Lagat

Day 9 (Tuesday 24th April, 2007)

08.30 – 10.00: Fish marketing and record keeping – Macharia / Boit
 10.00 – 10.30: Tea Break
 10.30 – 01.00: Fish processing and cooking –Boit / Mugo
 01.00 – 02.00: Lunch
 02.00 – 03.00: Course evaluation - Amadiva
 03.00 - 05.00: Closing ceremony

Day 10 (Wednesday 25th April, 2007)

Trainees leave

ATTACHMENT VII

Practicals program for the second training course in *Pond Management for Commercial Fish Farming* taught by the newly trained trainers. This course was held at Sagana Aquaculture Center from 16 - 26 April, 2007.

Practical

Form three groups – each group to run their own practical

Propagation of catfish

Day	Activity	Group one	Group two	Group three
Day1- 16 th (Monday)	Brood stock selection (catfish)	Av. Wt 250g female	Av. Wt 500g female	Mix the two female eggs- 500g & 250g
Day1-17 th (Tuesday)	Injection (catfish)	Same fish size pituitary gland donor – preserved	Same fish size pituitary gland donor – fresh	
Day 2-18 th (Wednesday)	Egg fertilization (catfish) Egg incubation	Dry fertilization Sample 20g eggs Egg tray Selection of gold fish broodstock & triggering	Wet fertilization Sample 20g eggs Kakabans Removing eggs from mouth brooding tilapia and incubation (hapanet)	Both Sample 20g eggs Pistia plant Removing eggs from mouth brooding tilapia and incubation (Aquaria)
Day 3 19 th (Thursday)	Monitoring hatching performance all groups - % hatchability			
Day 4-6 (20 th -22 nd) (Fri-sun)	Egg yolk absorption monitoring – sample and measure the size of the egg yolk & check using a microscope the opening of the mouth of the hatchlings on 2hr intervals & field trip			
Day 7 -23 rd (Monday)	Fry nursing Fish transportation	Rotifers Fish fry transportation	Dry diet e.g. fishmeal Fish fingerling transportation	Rotifers & fishmeal Broodstock fish transportation
Day 8 -24 th (Tuesday)	Fry nursing Fish preparation	Rotifers Fish cooking	Dry diet e.g. fishmeal Fish cooking	Rotifers & fishmeal Fish cooking
Day 9 (Wed)- 25 th	Trainees leave			

ATTACHMENT VIII

List of participants in the second training course in *Pond Management for Commercial Fish Farming* taught by the newly trained trainers. This course was held at Sagana Aquaculture Center from 16 - 26 April, 2007.

	NAME	GENDER	DESIGNATION	EST /NO.	STATION
1.	Florence Musieka	F	Fisheries Assistant	83076925	Busia
2.	Emmanuel Aiyabei	M	Senior Fish Scout	83009071	Nandi
3.	Margaret Kibocha	F	Senior Fish Scout	83070822	Kiganjo
4.	Margaret Wachera	F	Senior Fish Scout	80112463	Nyahururu
5.	Alice Mukami	F	Senior Fish Scout	83036894	Nyeri
6.	Abdi H. Golicha	M	Senior Fish Scout	82060125	Isiolo
7.	Titus Malusi	M	Senior Fish Scout	82090934	Kitui
8.	Silvia K. Gitonga	F	Senior Fish Scout	83076771	Meru South
9.	John G. Muchiri	M	Senior Fish Scout	80033952	Meru Central
10.	Peter K. Kahiga	M	Senior Fish Scout	82113782	Mbeere
11.	Peter M. Gathura	M	Senior Fish Scout	79045784	Laikipia
12.	David K. Waweru	M	Senior Fish Scout	81020156	Muranga
13.	Magdaline Kimani	F	Senior Fish Scout	74045682	Kiambu
14.	John M. Macharia	M	Senior Fish Scout	84129577	Laikipia
15.	Hannah Ngugi	F	Senior Fish Scout	84009272	Gatundu

ATTACHMENT IX

Resource persons and trainers involved in the second training course in *Pond Management for Commercial Fish Farming*, taught at Sagana Aquaculture Centre, from 16 - 26 April, 2007.

	NAME	GENDER	General Areas	
1.	Charles C. Ngugi	M	Pond Management	MUFISH
2.	Victoria Boit	F	Catfish production	MU Grad Student
3.	James Mugo	M	Hatchery Management	MU Grad Student
4.	William Kinyua	M	Hatchery Management	MU Technician
5.	Felix Lagat	M	Pond Management/ fish nutrition	FD -DFO Nyeri
6.	John Otiego	M	Trout culture/ HIV AIDS	FD-DFO Uasin Gishu
7.	Sammy Macharia	M	Pond Record Keeping/ enterprise budget	FD-FO Kisumu
8.	Rachel Kamau	F	Organization	FD-Sagana
9.	Judy Amadiva	F	Course Evaluation	FD-Nairobi HQs
10.	Stephen Irengi	M	Hatchery Attendance	FD- Sagana

**AQUACULTURE CRSP SPONSORSHIP OF THE SECOND INTERNATIONAL SYMPOSIUM ON CAGE
AQUACULTURE IN ASIA**

*Twelfth Work Plan/ Applied Technology & Extension Methodology Research 12 (12ATE12)
Final Report*

Published as Submitted by Contributing Authors

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ABSTRACT

The objectives of this activity were to organize a special session on environmentally-friendly integrated cage-cum-pond culture system at the Second International Symposium on Cage Aquaculture in Asia (CAA2), to provide travel support for five invited speakers on the special session from Aquaculture CRSP institutions in Asian countries, to provide travel support for four or more contributors from Aquaculture CRSP institutions in Asian countries, to provide three environment awards to recognize research that addresses environmental concerns of cage aquaculture, and to provide three best student paper prizes to recognize their academic performance.

Due to the limited papers, many sessions were merged. Thus, the session on environmentally-friendly integrated cage-cum-pond culture system was merged with the session on environmental impacts of cage aquaculture to be the session on environmental impacts and management. ACRSP researchers (Prof. James S. Diana and Prof. C. Kwei Lin) co-chaired the session. Among five invited speakers supported by ACRSP travel grants, two could not attend CAA2, due to urgent tasks in their organizations. Four Chinese researchers, including one MS student, were selected for ACRSP travel supports to attend CAA2. Environment Awards were given to three papers selected by a committee co-chaired Prof. James S. Diana and Prof. C. Kwei Lin, while the Best Student Paper Prizes were awarded equally to three papers selected by an independent committee appointed by Asian Fisheries Society.

INTRODUCTION

It is believed that cage aquaculture promises huge potential to meet increasing demands for seafood products. Modern cage aquaculture especially in the off-shore region has developed rapidly since late 1990s in Asia countries, while many challenges such as appropriate culture technologies and environmental impacts have been emerging as major concerns. A symposium was convened specifically to address concerns of cage aquaculture in Asia, the First International Symposium on Cage Aquaculture in Asia, and was held in 1999 in Taiwan (Liao and Lin 2000). To address emerging issues of cage aquaculture in Asia, the Second International Symposium on Cage Aquaculture in Asia (CAA2) was scheduled for 3-8 July 2006 in Zhejiang University, Hangzhou, China (www.caa2.org). Aquaculture CRSP researchers at the Asian Institute of Technology (AIT) played important roles in both symposia, and Aquaculture CRSP was invited as one of co-sponsors for CAA2. Environmentally friendly culture systems using cages integrated into ponds have been developed by Aquaculture CRSP in Asia. To promote these systems, a

special session was held at the second symposium in order to expand the Aquaculture CRSP influence in Asia, especially in China.

Travel support is very important to the researchers from developing countries to present their findings, understand the latest development, and exchange information with counterparts in international conferences. Aquaculture CRSP institutions in Asian countries benefit from the travel support, which ensures a strong international participation of Aquaculture CRSP host countries PIs.

The objectives of this activity were:

1. To organize a special session on environmentally-friendly integrated cage-cum-pond culture system at the Second International Symposium on Cage Aquaculture in Asia;
2. To provide travel support for five invited speakers on the special session from Aquaculture CRSP institutions in Asian countries;
3. To provide travel support for four or more contributors from Aquaculture CRSP institutions in Asian countries;
4. To provide three environment awards to recognize research that addresses environmental concerns of cage aquaculture.

SESSION ORGANIZATION AND TRAVEL GRANTS

Dr. Hillary Egna was appointed as honorable chairperson of CAA2, while Dr. Yang Yi served as vice chairperson of the organizing committee and chairperson of the scientific committee. However, both of them could not attend the symposium, due to health problem.

Due to the limited papers, many CAA2 sessions were merged. Thus, the proposed Aquaculture CRSP special session on Environmentally-Friendly Integrated Cage-Cum-Pond Culture System was merged with the session on Environmental Impacts of Cage Aquaculture to be the session on Environmental Impacts and Management. Aquaculture CRSP researchers, Prof. James S. Diana and Prof. C. Kwei Lin co-chaired the session. The following three papers related to the integrated cage-cum-pond culture systems were presented: (1) Integrated Cage-Cum-Pond Aquaculture Systems: A Conceptual Model; (2) Integrated Cage-Cum-Pond Culture System with *Clarias gariepinus* in Cages and Carps in Open Ponds; (3) Integrated Cage-Cum-Pond Culture Systems with High-Valued Stinging Catfish *Heteropneustes fossilis* in Cages and Low-Valued Carps in Open Ponds.

Among five invited speakers supported by ACRSP travel grants, Prof. James S. Diana, Prof. C. Kwei Lin, and Dr. Madhav K. Shrestha of Institute of Agricultural and Animal Science in Nepal attended CAA2, however, Dr. Anwara Begum Shelly, Director of Fisheries Program, CARITAS – a NGO in Bangladesh, and Dr. Nguyen Thanh Phuong of Can Tho University, Vietnam could not attend CAA2, due to urgent tasks in their organizations. Four Chinese researchers were selected for Aquaculture CRSP travel supports to attend CAA2. They are Prof. Su Yongquan of Xiamen University, Prof. Yao Weizi and Mr. Zheng Yonghua of Southwest University, and Miss Cao Ling, a MS student of Huazhong Agricultural University. Prof. Shao Qingjun of Zhejiang University helped all logistic arrangement for the participants supported by Aquaculture travel grants. The session was well attended by both international and domestic participants.

AQUACULTURE CRSP AWARDS

Prof. James S. Diana and Prof. C. Kwei Lin co-chaired a committee to select the Aquaculture CRSP Best Environment Awards, and the winners were:

1. First prize: Yang Yufeng and Fei Xiugeng from Jinan University, China. Their paper was entitled "Development of Mariculture and Bioremediation of Seaweeds in Chinese Coastal Waters."

2. Second prize: R. Mayerle, W. Windupranata and K.-J. Hesse from Kiel University, Germany. Their paper was entitled “Decision Support System for Sustainable Environmental Management of Marine Fish Farms.”
3. Third prize: Chongkim Wong, Chingyee Tse and Kingming Chan from Chinese University of Hong Kong, China. Their paper was entitled “DNA Damage as Biomarker for Assessing Effects of Suspended Solids on Cage-Cultured Marine Fish.”

A selection committee for Aquaculture CRSP Best Student Awards was appointed by Asian Fisheries Society (AFS) and consisted of Prof. Shi-Yen Shiau of National Taiwan Ocean University in Chinese Taipei, Prof. Fatimah Md. Yusoff of Universiti Putra Malaysia in Malaysia, Prof. Roshada Hashim of Universiti Saint Malaysia in Malaysia, and Prof. Joe-Yoon Jo of Pukyong National University in Korea. The following papers were selected as Best Student Paper Awards without ranking:

1. Cai Huiwen* and Sun Yinglan from Ocean University of China. Their paper was entitled “Environmental Carrying Capacity of Cage Aquaculture Based on Dry Matter Conversion Rate in Xiangshan Harbor.”
2. Jiang Yusheng* and Wu Xinzong from Zhejiang University of China. Their paper was entitled “Characterization of a Rel/NF- κ B Homologue in a Gastropod Abalone, *Haliotis Diversicolor Supertexta*.”
3. Xu Shannan*, Zhang Hanye, Wen Shanshan, Luo Kun and He Peimin from Shanghai Fisheries University of China. Their paper was entitled “Integrating Seaweeds into Marine Fish Cage Culture Systems: A Key Towards Sustainability.”

All winners of Best Student Paper Awards were Chinese students marked with * in above list, because there were no student participants from other countries.

ANTICIPATED BENEFITS

Aquaculture CRSP researchers benefited from the presentations made in the symposium, while other participants from all over the world, particularly Asian countries, also benefited from the achievements of Aquaculture CRSP.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support from the Asian Institute of Technology, Thailand, Zhejiang University, China, and Asian Fisheries Society.

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PROMOTING ENVIRONMENTALLY-FRIENDLY INTEGRATED CAGE-CUM-POND CULTURE SYSTEMS

Twelfth Work Plan, Applied Technology & Extension Methods 13(12ATE13)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

The objectives of this activity are to produce a manual on the environmentally friendly integrated cage-cum-pond systems developed by Aquaculture CRSP, to produce promotional brochures in different languages, and to promote the integrated cage-cum-pond systems through the manual, promotional brochures and workshops to be held in different countries.

A manual on environmentally friendly integrated cage-cum-pond culture systems and four brochures on the integrated cage-cum-pond culture systems in Chinese, Bengali, Nepalese and Vietnamese languages have been developed. A workshop was combined with the session on environmental impacts of cage aquaculture in the 2nd Symposium on Cage Aquaculture in Asia held in Hangzhou, China on 3-8 July 2006, during which three papers on the integrated cage-cum-pond culture systems were presented. Three workshops were held in Kathmandu of Nepal on 8 June 2007, in Bangladesh Agricultural University, Mymensingh of Bangladesh on 14 June 2007, and in Can Tho University, Can Tho City of Vietnam on 26 June 2007.

INTRODUCTION

Integrated cage-cum-pond culture is a system in which high-valued fish species are fed with artificial diets in cages suspended in ponds, where filter-feeding fish species are stocked to utilize natural foods derived from cage wastes. This integrated system has been developed and practiced using combinations of catfish-tilapia (Lin 1990; Lin and Diana 1995) and tilapia-tilapia (Yi et al. 1996; Yi 1997; Yi and Lin 2000, 2001) in Thailand. Although cages were set up using Nile tilapia monoculture ponds in all previous work mentioned above, this integrated system can be applied to polyculture ponds. In polyculture, ponds are stocked with several species of different feeding

habits together. In mixed culture, it is impossible to target feeding to only high-valued species, because all fish consume the feed resulting in economic inefficiency unless an integrated system is adopted. Compared to nutrient utilization efficiency of about 30% in intensive culture systems (Beveridge and Phillips 1993; Acosta-Nassar et al. 1994), the nutrient utilization efficiency could reach more than 50% in integrated cage-cum-pond systems, resulting in release of less nutrients to the surrounding environment (Yi 1997). Therefore, the integrated cage-cum-pond culture system has been regarded as an environmentally friendly aquaculture system.

Recently, Aquaculture CRSP has funded on-station and on-farm trials with different high-valued local species in cages suspended in carp polyculture ponds in Bangladesh, Nepal, and Vietnam. The participating farmers have shown much interest in these integrated cage-cum-pond systems, which provide opportunities for small-scale poor farmers to use their limited resources to culture a small amount of high-valued species in their ponds, thus generating more income and improve their livelihood. CARITAS, a Bangladesh NGO, conducted on-farm trial in its network farmers' ponds, has become convinced by the encouraging results and has decided to promote this integrated system through its network.

Therefore, the overall objective of the proposed activities was to foster environmentally friendly aquaculture by promoting integrated cage-cum-pond culture systems. Specific objectives were:

1. To produce a manual and brochures in local languages on integrated cage-cum-pond systems developed by Aquaculture CRSP;
2. To hold workshops on integrated cage-cum-pond systems in Bangladesh, China, Nepal and Vietnam;
3. To promote integrated cage-cum-pond systems developed by Aquaculture CRSP through the developed manual, promotional brochures produced in different languages, and the planned workshops.

Activity 1: Producing a manual for integrated cage-cum-pond culture systems

A manual on the integrated cage-cum-pond culture systems has been developed. The manual has five major chapters: chapter 1 - traditional aquaculture systems (cage culture; pond culture; environmental impacts of aquaculture effluents; and integrated fish/livestock or poultry culture system); chapter 2 - principles and concepts of integrated cage-cum-pond culture (nutrient flow; nutrient recycling; ratios of caged fish and open-pond fish); chapter 3 - practical considerations for integrated cage-cum-pond culture systems (species selection for cages; species selection for ponds; cage design, construction, and placement in ponds; feed and feeding management); chapter 4 - examples of cage-cum-pond culture systems (catfish in cages and tilapia in ponds; fattening tilapia in cages and nursing tilapia in ponds; other high-valued species in cages and carps in ponds); chapter 5 – prospects for environmentally friendly, integrated cage-cum-pond culture systems. The manual has been printed and distributed through workshops, as well as by mail to aquaculture agencies and institutions.

Activity 2: Producing promotional brochures for integrated cage-cum-pond culture systems in different languages

Three promotional brochures have been produced in Bengali, Chinese, Nepalese and Vietnamese. The brochure in each of the above languages was printed with 500 copies, distributed at workshops and mailed to aquaculture agencies and institutions in those countries.

Activity 3: Conducting four workshops on integrated cage-cum-pond culture systems

Workshop in China

This workshop was combined with the session on environmental impacts of cage aquaculture in the 2nd Symposium on Cage Aquaculture in Asia held in Hangzhou, China on 3-8 July 2006. Aquaculture CRSP researchers Prof. James Diana and Prof. C. Kwei Lin co-chaired the session. During this session, three papers on integrated cage-cum-pond culture systems were presented.

Workshop in Nepal

A one-day workshop was held on 8 June 2006 at the Central Fisheries Building, Balaju, Kathmandu of Nepal, and organized jointly by Aquaculture CRSP, Institute of Agriculture and Animal Science of Nepal (IAAS) and Nepal Fisheries Society (NEFIS).

The workshop was attended by 36 participants among which 7 were women, representing National Academy of Science and Technology, Department of Agriculture (DOA), NARC, Himalayan College of Agricultural Sciences and Technology, Tribhuvan University, IAAS, farmers' group, and Asian Institute of Technology (AIT) (Table 1).

The workshop was opened by a welcome address by Dr. T.B. Gurung, Chief of Fisheries Research Division, Godawari, Lalitpur, National Agriculture Research Council (NARC), and vice president of Nepal Fisheries Society (NEFIS), followed by self-introduction of all participants. Dr. Madhav K. Shrestha (HCPI) from IAAS briefed participants on the objectives of the workshop, while Dr. Yang Yi of AIT gave a presentation to introduce the history, activities and achievements of ACRSP during the past 25 years.

The technical session was chaired by Mr. K.K. Upadhyaya, senior fisheries development officer, Fisheries Development Centre Fatepur of DOA and president of NEFIS. Dr. Yang Yi gave a presentation entitled "Integrated Cage-Cum-Pond Culture Systems: Concept, Practices and Perspectives," sharing the ACRSP work on integrated cage-cum-pond culture in Thailand. Dr. Madhav K. Shrestha presented applications of integrated cage-cum-pond culture systems under conditions in Nepal. His first presentation was entitled "Integrated Cage-Cum-Pond Culture Systems for Fattening Large Mixed-Sex Nile Tilapia in Cages and Breeding and Nursing Tilapia in Open-Pond," and the second was entitled "Integrated Cage-Cum-Pond Culture Systems for African Catfish in Cages and Carps in Open Pond." An open discussion followed the technical presentations, and facilitated by Mr. R. N. Mishra, joint secretary of NEFIS. The technical session ended with closing marks by Mr. K.K. Upadhyaya.

Workshop in Bangladesh

A one-day workshop was held on 14 June 2006 at the Hotel Civic, Gulshan, Dhaka of Bangladesh, and organized jointly by Aquaculture CRSP, Bangladesh Fisheries Research Forum (BFRF) and Voluntary Organization for Social Development (VOSD), an NGO in Bangladesh.

The workshop was attended by 29 participants among which 4 were women, representing government agencies - Bangladesh Agricultural Research Council (BARC), and Department of Fisheries; international organizations - WorldFish Center; NGOs - CARITAS, Chandradip Development Society, Dulai Jana Kallyan Sangstha, Peoples Organization for Sustainable Development, PROSHIKA, TMSS, VOSD, and Welfare Efforts; academic institutions - BFRF, Bangladesh Agricultural University (BAU), Bangladesh Fisheries Research Institute, Khulna University, Rajshahi University, Shere-Bangla Agricultural, University, University of Chittagong, University of Dhaka and Asian Institute of Technology; and farmers (Table 2).

The workshop was opened with a welcome address by Dr. Khabir Ahmed, member director of BARC and BFRF secretary, followed by the self-introduction of all participants. Dr. Md. Abdul Wahab (HCPI), BAU professor and BFRF president, briefed participants on objectives of the workshop, while Dr. Yang Yi of AIT gave a presentation to introduce the history, activities and

achievements of ACRSP during the past 25 years. Dr. Malcolm Beveridge, discipline director of the WorldFish Center in Cairo, Egypt, shared his experiences of cage culture in both Bangladesh and other parts of the world.

The technical session was chaired by Dr. Md. A. Wahab. Dr. Yang Yi gave a presentation entitled “Integrated Cage-Cum-Pond Culture Systems: Concept, Practices and Perspectives.” sharing the ACRSP work on the integrated cage-cum-pond culture systems in Thailand. Mr. Nurun Nabi Mandal, BAU research fellow, gave his presentation on “Compression between Cage and Pond Production of Climbing Perch and Tilapia under Three Management Systems.” Ms Tamanna Khatun of OVSD presented the application of integrated cage-cum-pond culture system with the title of “Integrated Cage-Cum-Pond Culture System for Small Women Farmers.” Mr. Md. Asaduzzaman, BAU research fellow, presented “Integrated Cage-Cum-Pond Culture System with High Valued Stinging Catfish in Cages and Low Valued Carps in Open Ponds.” The last speaker was Dr. Anwara Begum Shelly, Director of CARITAS Fisheries Program, who gave a presentation entitled “Cage-Cum-Pond Culture Systems for Small Farmers.” An open discussion followed the technical presentations. The technical session ended with closing marks by Dr. Md. A. Wahab.

Workshop in Vietnam

A one-day workshop was held on 26 June 2006 at Can Tho University (CTU) of Vietnam, which was organized jointly by Aquaculture CRSP and CTU.

The workshop was attended by 50 participants among which 10 were women, representing provincial and district government agencies, private sector, farmers and academic institutions from Can Tho City, An Giang province, Hau Giang province, Dong Thap province, and Vinh Long province as well as Asian Institute of Technology (Table 3).

The workshop was opened with a welcome address by Dr. Nguyen Thanh Phuong (HCPI) of Can Tho University, followed by self-introduction of all participants. Dr. Nguyen Thanh Phuong briefed participants on objectives of the workshop, while Prof. C. Kwei Lin of AIT gave a presentation to introduce the history, activities and achievements of ACRSP during the past 25 years.

The technical session was chaired by Dr. Nguyen Thanh Phuong, who gave a presentation of the ACRSP work entitled “Culture of Climbing Perch in Cage-Cum-Tilapia in Open Pond.” Prof. C. Kwei Lin gave three presentations: “Integrated Cage-Cum-Pond Culture Systems: Concept and Prospects,” “Raising Catfish and Tilapia in the Integrated Cage-Cum-Pond Culture System” and “Nursing and Fattening Tilapias in the Integrated Cage-Cum-Pond Culture System.” These presentations shared the experience on integrated cage-cum-pond culture systems in Thailand. After that, Dr. Duong Nhut Long and Dr. Bui Minh Tam of Can Tho University shared their work on the applications of the integrated cage-cum-pond culture systems using snakehead and marble goby, with the titles of “Culture of Snakehead in Hapa-Cum-Tilapia in Ponds” and “Culture of Marble Goby in Cage-Cum-Tilapia in Ponds,” respectively. An open discussion followed the technical presentations. Finally, the technical session ended with closing marks by Prof. C. Kwei Lin and Dr. Nguyen Thanh Phuong.

ANTICIPATED BENEFITS

The technology of the integrated cage-cum-pond culture system will provide small-scale farmers an opportunity to generate more income and improve their livelihood using their scarce resources; and will benefit small-scale farmers in Asian and other countries, where the integrated systems can be practiced.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support from the Asian Institute of Technology, Thailand; Zhejiang University, China; Nepal Fisheries Society and Institute of Agricultural and Animal Science, Nepal; Bangladesh Agricultural University at Mymensingh, Bangladesh Fisheries Research Forum, and Voluntary Organization for Social Development, Bangladesh; and Can Tho University, Vietnam.

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Table 1. List of participants at the Workshop on Cage-cum-Pond Integrated System for Enhancing Fish Productivity and Income to Small Farmers held on June 8, 2007 at Kathmandu, Nepal

Name	Gender	Position and Institution
Mr. Krishna Gopal Rajbanshi	Male	Academician, National Academy of Science and Technology, Kathmandu
Dr. Deep Bahadur Swar	Male	Director General, Department of Agriculture (DOA), Kathmandu
Dr. Adarsha Pradhan	Male	Director, Livestock and Fisheries, National Agricultural Research Council (NARC), Kathmandu
Mr. Dharani Man Singh	Male	Program Director, Directorate of Fisheries Development (DOFD), DOA, Kathmandu
Mrs. Purna Dhungana	Female	Fisheries Development Officer, DOFD, Kathmandu
Mr. Narayan Giri	Male	Fisheries Development Officer, DOFD, Kathmandu
Mr. Gagan BN Pradhan	Male	Program Chief, National Inland Fisheries and Aquaculture Development (NIFAD) Program, Balaju, DOA
Mr. Resham Raj Dhital	Male	Senior Fisheries Development Officer, NIFAD Program, Balaju, DOA
Mr. Deepak Bhusal	Male	Fisheries Development Officer, NIFAD Program, Balaju, DOA
Mr. Shyam Prasad Rijal	Male	Agriculture Extension Officer, NIFAD Program, Balaju, DOA
Mr. Rajendra Kumar K. C.	Male	Senior Fisheries Development Officer, Central Fisheries Laboratory, DOA
Mr. Shankar Dahal	Male	Fisheries Development Officer, Central Fisheries Laboratory, DOA
Dr. Rajesh Thakur	Male	Fisheries Development Officer, Central Fisheries Laboratory, DOA
Mr. Jaya Kishore Mandal	Male	Senior Fisheries Development Officer, Fisheries Development Centre Dhangadhi, DOA
Mr. Rama Nanda Mishra	Male	Senior Fisheries Development Officer, Fisheries Development Centre Bhairahawa , DOA
Mr. Shiva Nanda Yadav	Male	Senior Fisheries Development Officer, Fisheries Development and Training Centre Janakpur, DOA
Mr. Kishore Kumar Upadhyaya	Male	Senior Fisheries Development Officer, Fisheries Development Centre Fattepur, DOA
Mr. Hira Lal Bhusal	Male	Fisheries Development Officer, District Agriculture Development Office, Bharatpur, Chitwan, DOA
Mr. Ram Prasad Pant	Male	Fisheries Development Officer, Fisheries Development Center, Bhandara, Chitwan, DOA
Dr. Ash Kumar Rai	Male	Aquaculture Professional (retired from NARC), Lalitpur
Dr. Tek Bahadur Gurung	Male	Chief, Fisheries Research Division, Godawari, Lalitpur, NARC
Mrs. Neeta Pradhan	Female	Scientist, Fisheries Research Division, Godawari, Lalitpur, NARC
Mrs. Asha Rayamajhi	Female	Scientist, Fisheries Research Division, Godawari, Lalitpur, NARC
Mr. Suresh Kumar Wagle	Male	Senior Scientist, Fisheries Research Center, Begnas, Pokhara, NARC
Mr. Sadhu Ram Basnet	Male	Senior Scientist, Fisheries Research Center, Trishuli, NARC
Mrs. Shushila KC	Female	Lecturer, Himalayan College of Agricultural Sciences and Technology, Gathaghar, Kathmandu

Table 1 (continued)

Name	Gender	Position and Institution
Dr. Surya Ratna Gubhaju	Male	Associate Professor, Central Department of Zoology, Tribhuvan University
Dr. Madhav K. Shrestha	Male	Associate Professor, Department of Aquaculture, Rampur Campus, Institute of Agriculture and Animal Science (IAAS)
Mr. Dilip Kumar Jha	Male	Associate Professor, Department of Aquaculture, Rampur Campus, IAAS
Mr. Arbind Kumar Singh	Male	Associate Professor, Department of Aquaculture, Rampur Campus, IAAS
Mr. Chudamani Pandey	Male	Lecturer, Lamjung Campus, IAAS
Mr. Shovan Mahato	Male	Farmer, Kathar, Chitwan
Mrs. Hari Maya Chaudhary	Female	Farmer, Kathar, Chitwan
Mrs. Gunja Chaudhary	Female	Farmer, Kathar, Chitwan
Mrs. Devi Dahit	Female	Farmer, Kathar, Chitwan
Dr. Yang Yi	Male	Associate Professor, Asian Institute of Technology, Thailand

Table 2. List of participants at the Workshop on Cage-cum-Pond Integrated System for Enhancing Fish Productivity and Income to Small Farmers held on June 14, 2007 at Dhaka, Bangladesh.

Name	Gender	Position and Institution
Dr. Khabir Ahmed	Male	Member Director (Fisheries), Bangladesh Agricultural Research Council, Dhaka
Dr. Md. Abdul Wahab	Male	Professor, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
Dr. M.A Salam	Male	Professor, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
Md. Asaduzzaman	Male	Research fellow, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
Md. Narunnabi Mandal	Male	Research fellow, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh
Dr. M. S. Shah	Male	Professor, FMRT Discipline, Khulna University
Dr. Niamul Naser	Male	Associate Professor, Department of Zoology University of Dhaka, Dhaka
Md. Akhter Hossain	Male	Associate Professor, Department of Fisheries, Rajshahi University, Rajshahi
Dr. Mohammed Zafar	Male	Institute of Marine Sciences & Fisheries, University of Chittagong, Chittagong
Dr. Anwara Begum Shelly	Female	Director, Fisheries Program, CARITAS
Dr. Khan Kamal Ahmed	Male	Senior Scientific Officer, Reverine Station, Bangladesh Fisheries Research Institute, Chandpur
Md. Rabiul Awal	Male	Scientific Officer, Reverine Station, Bangladesh Fisheries, Research Institute, Chandpur
Ms. Tamanna Khatun	Female	Director Fisheries, Voluntary Organization for Social Development (VOSD), Dhaka
Mr. AFM Rajib Uddin	Male	Director, Peoples Organization for Sustainable Development (POSD), Rajshahi
Ms. Sharifa Khatun	Female	Director, Welfare Efforts (WE), Jhenaidah
Ms. Jahanara Begum Shopna	Female	Director, Chandradip Development Society (CDS), Barisal
Md. Altaf Hossain	Male	Programme Coordinator (Fisheries), PROSHIKA, Dhaka
Mr. Borkot Ali Bokul	Male	Director, Dulai Jana Kallyan Sangstha (DJKS), Pabna
H. M. Idris	Male	Assistant Director, TMSS, Bogra
Md. Azizul Hakim	Male	Cage farmer, Rajshahi
Md. Samsuzzoha	Male	Cage farmer, Rajshahi
Md. Mohidul Islam	Male	Cage farmer, Rajshahi
Md. Showkat Ali	Male	Cage farmer, Dhaka
Mr. Shamim Ahmed	Male	Department of Fisheries, Dhaka
Mr. A.M. Shahabuddin	Male	Lecturer, Shere-Bangla Agricultural; University, Dhaka
Dr. Malcolm Beveridge	Male	Discipline Director, WorldFish Center, Cairo, Egypt
Mr. Benoy Kumar Barman	Male	Coordinator, WorldFish Center, Bangladesh & South Asia Office, Dhaka
Dr. Md. Akhteruzzaman	Male	Coordinator, Bangladesh Fisheries Research Forum, Dhaka
Dr. Yang Yi	Male	Associate Professor, Asian Institute of Technology, Thailand

Table 3. List of participants at the Workshop on Cage-cum-Pond Integrated Systems held on June 26, 2007 at Can Tho, Vietnam.

Name	Gender	Position and Institution
To Minh Nguyet	Male	Fisheries and Aquaculture Agency, Can Tho City
Nguyen Thi Le Hoa	Female	Agriculture Extension Center, Can Tho City
Cao Ngoc Loi	Male	Agriculture Extension Station, O Mon district, Can Tho City
Tran Van Trac	Male	Agriculture Extension Station, Vinh Thanh district, Can Tho City
Nguyen Thi Hong Nhien	Female	Agriculture Extension Station, Vinh Thanh district, Can Tho City
Ha Van Duyen	Male	Farmer, Can Tho City
Nguyen Van Ut	Male	Farmer, Can Tho City
Nguyen Tan Cuong	Male	Farmer, Can Tho City
Nguyen Thi Ngoc Ha	Female	Aquaculture Seed Center , An Giang Province
Nguyen Van Dong	Male	Agriculture Extension Station, Tan Chau district, An Giang Province
Tran Van Ba	Male	Farmer, An Giang Province
Nguyen Thanh Hung	Male	Farmer, An Giang Province
Danh Tan Lanh	Male	Farmer, An Giang Province
Nguyen Thanh Phong	Male	Agriculture Extension Station, Tinh Bien district, An Giang Province
Dang Ngoc Giao	Male	Fisheries and Aquaculture Agency, Hau Giang Province
Nguyen Van Thong	Male	Agriculture Extension Station, Long My district, Hau Giang Province
Tong Buu Son	Male	Agriculture Extension Station, Vi Thuy district, Hau Giang Province
Ngo Minh Long	Male	Agriculture Extension Station, Chau Thanh, Hau Giang Province
Nguyen Van Son	Male	Agriculture Extension Station, Chau Thanh, Hau Giang Province
Nguyen Ngoc Dung	Male	Agriculture Extension Station - Chau Thanh, Hau Giang Province
Phan Quoc Thu	Male	Agriculture Extension Station - Chau Thanh, Hau Giang Province
Nguyễn Văn Ó	Male	Farmer, Hau Giang Province
Dinh Minh Truong	Male	Farmer, Hau Giang Province
Cao Thanh Nê	Male	Farmer, Hau Giang Province
Nguyen Van Xuan	Male	Agriculture Extension Station, Lai Vung district, Dong Thap Province
Tran Thi Thuy Hang	Female	Agriculture Extension Station, Cao Lanh district, Dong Thap Province

Table 3 (continued)

Name	Gender	Position and Institution
Nguyen Thanh Phong	Male	Agriculture Extension Station, Hong Ngu district, Dong Thap Province
Pham Van Doan	Male	Farmer, Dong Thap Province
Nguyen Van Luc	Male	Farmer, Dong Thap Province
Nguyen Vinh Lam	Male	Farmer, Dong Thap Province
Nguyen Thi Ngoc Lan	Female	Agriculture Extension Center, Vinh Long Province
Tang Khanh Hung	Male	Agriculture Extension Station, Long Ho district, Vinh Long Province
Tran Quy Xuyen	Male	Agriculture Extension Station, Vung Liem district, Vinh Long Province
Nguyen Thi Kim Loan	Female	Agriculture Extension Station, Vinh Long Province
Nguyen Thai Khoa	Male	Famer, Vinh Long Province
Nguyen Van Nhu	Male	Farmer, Vinh Long Province
Nguyen Duc Tien	Male	Farmer, Vinh Long Province
Le Thi Cam Nhung	Female	Farmer, Vinh Long Province
Nguyen Khai Dinh	Male	Staff, Cty VEMEDIM Company, Can Tho City
Nguyen Thanh Phuong	Male	Can Tho University, Can Tho City
Duong Nhut Long	Male	Can Tho University, Can Tho City
Bui Minh Tam	Male	Can Tho University, Can Tho City
Nguyen Thanh Hieu	Male	Can Tho University, Can Tho City
Nguyen Van Trieu	Male	Can Tho University, Can Tho City
Dang Huu Tam	Male	Can Tho University, Can Tho City
Le Son Trang	Male	Can Tho University, Can Tho City
Pham Thi Cam Lai	Female	Can Tho University, Can Tho City
Nguyen Thi Ngoc Lien	Female	Can Tho University, Can Tho City
Duong Doan Trang	Female	Can Tho University, Can Tho City
C. Kwei Lin	Male	Asian Institute of Technology, Thailand

AQUACULTURE CRSP SUPPORT FOR IIFET 2006 PORTSMOUTH

Twelfth Work Plan, Applied Technology & Extension Methodologies 15 (12ATE15)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

Under Memorandum of Understanding No. RD009Q-01, ACRSP provided support to the international Institute of Fisheries Economics & Trade to strengthen the breadth and depth of aquaculture economics presentations at its thirteenth biennial conference held in Portsmouth, UK, in July of 2006. Under the project, three best student paper prizes were awarded six individuals received travel support enabling them to attend the conference, and nine conference sessions (some with multiple sections) on a variety of aquaculture-related topics were organized.

INTRODUCTION

The USAID-funded Aquaculture Research Collaborative Support Program provided financial support to the 2006 biennial conference of the International Institute of Fisheries Economics and Trade (IIFET) in the amount of \$20,000, over the period July 1, 2005 through July 31, 2006. The primary goals of this activity was to strengthen the IIFET network's capacities in aquaculture economics and seafood marketing, enable the development of improved international research relationships, to build participation both at the conference and beyond in the area of aquaculture economics and social science development, and to improve recognition of the significance of the role of aquaculture in meeting world demand for fish products.

To accomplish these goals, activities included offering a variety of awards designed to enable and encourage participants, especially those from developing countries, to better participate in the conference, to share their research and benefit from exposure to the research of others.

Two types of awards were offered: pre-conference professional awards, and best student paper awards.

Under the former category, participants were selected based on their submission of an abstract describing their presentation on a relevant aquaculture-related topic; selection was carried out by IIFET Executive Director Ann Shriver in consultation with the Conference Scientific Committee. Of the selected participants, four received assistance and were able to attend the conference:

Mr. Abdoukarim Esmaili of Shiraz University, Iran presented Assessing the Competitiveness of Shrimp Farming in Iran: Using PAM Approach

Dr. Julita Ungson of the College of Aquatic Sciences and Applied Technology, Mariano Marcos State University, Philippines presented An Economic Assessment of Sea Urchin (*Tripneustes gratilla*) Culture

Dr. Taiwo Mafimisebi of the Federal University of Technology, Akure, Nigeria presented Comparative Yield Performance of Upland and Mangrove Aquacultural Farms in Selected Maritime States of South West Nigeria and Are Middlemen Really Exploitative? Empirical Evidence from the Sun-Dried Fish Market in South West Nigeria.

Mr. Francis Tazoacha of Action Centre for Rural Community Development, Cameroon presented *Creating Better Market Avenues for Aquatic Products in Sub Saharan Africa in the Wake of Globalization*

Each of these participants was given only partial travel support under the grant, and was able to leverage the funds provided with additional grants or funds from their own institutions to cover the additional costs. For example, Dr. Mafimisebi was given \$900 toward his airfare, and covered his own lodging, registration, and local travel expenses. Dr. Ungson received only lodging and registration support, and covered her own airfare and local travel. Because of this leveraging, we were also able to allocate money budgeted for international travel grants to two of the students who received awards but did not have travel support, and would otherwise have been unable to participate (see below).

Student Prizewinners: In collaboration with ACRSP staff, the IIFET Executive Director set up a review panel of distinguished experts in international aquaculture economics, comprised of Dr. Trond Bjørndal (Centre for Fisheries Economics, Bergen, Norway, and Worldfish Center Board Member), Dr. James Young (University of Stirling, Scotland), and Dr. Porter Hoagland (Woods Hole Oceanographic Institute, USA). Prior to the conference, IIFET solicited submissions of papers in competition for the best student papers in aquaculture. A first, second, and third place award were envisioned.

Nine papers were submitted. The award winners selected were:

1. First Prize (\$400): Ajao Olajide, Ladoke Akintola University of Technology, Nigeria, for *Non Radial Technical Efficiency of Fish Farms in Oyo State, Nigeria*.
2. Second Prize (\$300): Poulomi Bhattacharya, Institute for Social and Economic Change, India, for *Comparative Economics of Traditional Vs. Scientific Shrimp Farming Systems: A Study of Smallholders' Shrimp Culture in West Bengal*
3. Third Prize (\$200): Mohottala G. Kularatne, University of Portsmouth, UK, for *Investigation of Socioeconomic Characteristics of Agricultural Communities in Relation to the Development of Culture-Based Fisheries in Non-Perennial Reservoirs of Sri Lanka*

We provided lodging, student registration, plus \$500-\$600 toward airfare and other costs to the first and second prize winners. This enabled the two who were from distant locations to travel to, and participate in the conference, supplemented by partial travel support from their own institutions, given when they learned that prizes and partial support had been offered.

Each supported participant was asked for a brief statement of the main advantages they had gained through participation in the conference. They provide very specific evidence of the effects on these individuals' careers and lives of their participation in IIFET 2006 Portsmouth.

To summarize, the participants were able to present their own research, in varying stages of completion and levels of proficiency, and receive valuable input about the analytical techniques they are using. Some met others who had carried out similar research in a different region; some received and some provided critical feedback on work presented at the conference. Several longer-term research relationships and projects have been developed through contacts made at this conference. In turn, the participation of the supported students and professionals increased the geographic breadth of the conference.

Perhaps more importantly, the offering of awards attracted not only these seven participants, but additional presenters in a wide variety of aquaculture-related topics. Forty-eight abstracts were accepted under a variety of aquaculture topics; many more fell under seafood consumption, labeling and marketing topics relevant to aquaculture as well as fisheries products.

Aquaculture-specific session titles at the IIFET 2006 Portsmouth conference included:

Aquaculture Policy, Planning and Development (sessions 1 and 2)
The Great Salmon Run: Competition Between Wild and Farmed Salmon
Use of Fishmeal in Salmon Aquaculture: Sustainability, PCB's and International Trade
Aquaculture-Fisheries Interactions
Aquaculture Pests and Diseases
Aquaculture and the Environment
Aquaculture Modeling
Aquaculture Economic Evaluation (sessions 1, 2, and 3)
Aquaculture Markets (sessions 1 and 2).

Additional activities undertaken under the auspices of the grant included supporting staff time and involvement to organize the review processes, administer the travel support, and enable technical staff to be present at the conference to facilitate the collection of proceedings documents.

The provision of this grant enabled IIFET to continue in the tradition of building participation in the application of economic analysis to the many issues and problems facing aquaculture globally. This traditions was established when the first assistance was provided in 2000. While the assistance has focused on developing country participants, as demonstrated by the list of sessions above, our coverage of aquaculture and related topics has become quite global in scope, covering topics and developing linkages between and among researchers from all regions.

WORKSHOPS FOR THE CULTIVATION OF NEW SPECIES IN BRAZIL AND PERU

Twelfth Work Plan, Applied Technology & Extension Methods 16 (12ATE16)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

Workshop on “Larviculture of Neotropical Fish” took place in Manaus June 2 and speakers included Portella, M., Jomori R. (CAUNESP) and Dr. Bernardo Baldisserotto (Federal University of Santa Maria), who were supported by CRSP funds. It was attended by at least 100 participants, graduate students, local producers, and researchers from Peru, Bolivia, Ecuador, Venezuela and Colombia. Two investigators from INPA presented their findings on propagation of Amazonian fish and live food composition of early stages of tropical fishes. The second workshop organized by M. Sandoval took place in the auditorium of the Universidad Nacional Agraria de la Selva (UNAS) and there was over 140 persons in attendance, among them 15 producers, 65 students and 45 other professionals.

INTRODUCTION

To accelerate the delivery of research results to farmers and other aquaculture professionals in the form of outreach and extension modules, we organized several workshops, namely in Manaus, Brazil, and Tingo Maria and Lima, Peru, between May and July 2007. Specifically, to continue long-term training of graduate students and carry out workshops on reproduction and nutrition of tropical fishes, and a new challenging aquaculture species in tropical Amazon region, we included speakers who addressed culture technology, and physiological aspects of piraruku (paiche) (*Arapaima gigas*) and arowana (*Osteoglossum sp.*).

RESULTS

Workshop on “Larviculture of Neotropical Fish” took place in Manaus on Saturday, June 2 and was organized by Portella, M., Val, V. and K. Dabrowski. Three speaker at the workshop, Portella, M., Jomori R. (CAUNESP) and Dr. Bernardo Baldisserotto (Federal University of Santa Maria) were supported by CRSP funds. It was attended by at least 100 participants, mostly graduate students from Federal University in Manaus, but also by local producers, researchers and students from Peru, Bolivia, Ecuador, Venezuela and Colombia. Drs. A. Honckzarick and Leite R.G. from INPA presented their findings on propagation of Amazonian fish and live food composition of

early stages of tropical fishes in the wild and in semi-intensive ponds. Drs. M.C. Portella and Jamori R. described physiology of early stages of pacu (*Piaractus mesopotamicus*) and surubims (*Pseudoplatystoma*), their rearing in captivity (hatchery, laboratory) and intensive ponds, and the economic aspects of such alternatives in practical farming conditions. Dr. M. Jaroszewska presented a paper on “Comparative aspects of differentiations of digestive tract in acipenserid, lepisosteid and teleost fishes” in part based on research with longnose gar (*Lepisosteus osseus*) and silver arowana (arwana) (*Osteoglossum bicirrhosum*) funded by CRSP projects.

The workshops organized by M. Sandoval were devoted to possible alternatives in aquaculture and some of the experiences with raising larval and juvenile tropical fish, such as pacu (*Piaractus mesopotamicus*) and surubim-catfish (*Pseudoplatystoma* sp.) in our laboratory in Columbus. The second workshop in Tingo Maria took place in the auditorium of the Universidad Nacional Agraria de la Selva (UNAS) and Vice Rector Wilson Castillo opened the meeting and welcomed participants. There were over 140 persons in attendance to the two workshops, among them 15 producers, 65 students and 45 other professionals. In particular, presentations by two biologists from Instituto de Investigaciones Amazonia Peruana (IIAP Pucallpa), Carmela Rebaza and Mariano Rebaza dealing with rearing in ponds and captivity of larval and juvenile paiche, and experiences in the nutrition of paiche were of major interest to participants. Dr. Sandoval presented a paper on “Strategies of development of paiche aquaculture in the Valley of Alto Huallaga.” Dr. Jaroszewska also presented our first findings on yolk utilization in larval arowana (*Osteoglossum bicirrhosum*) in comparison to more ancient, non-teleostean fish such as *Lepisosteus* and *Acipenser*. Eliana Villafana Salinas from Tingo Maria presented traditional pond rearing of paiche juveniles and M. Sandoval reviewed general aspects of sex determination in juvenile paiche, some aspects of nutrition but concentrated on the use of modern proteomic tools in identification of interactions between feeding and fish growth.

Guillermo Alvarez, Maria Esther Palacios and Luz Valenzuela, San Marcos University in Lima organized the workshop on “Reproduction, Nutrition and Sustainable Culture of Amazonian Fishes”. We essentially delivered the same presentations as in Tingo Maria in a more detailed manner to approximately 60 people in attendance. There were many researchers among the audience from other universities in Lima as well as investigators from Instituto de Investigaciones Amazonia Peruana (IIAP Pucallpa).

CONCLUSIONS

We received enormous satisfaction observing enthusiasm and interest among the participants when results of our research with tropical species were presented. We are convinced that there was no doubt left that the collaborative effort between the host countries researchers and investigators from the USA allows an accelerated progress in research projects and these findings translate into practical applications in the field. These workshops also added new institutions and researchers (University of Altiplano, Puno, Peru) into possible collaborators for A-CRSP in the future.

ACRSP SUPPORT FOR DEVELOPMENT OF AQUACULTURE ECONOMICS

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Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

The International Institute of Fisheries Economics & Trade (IIFET) is an international forum for the exchange of information and research on the economics of aquaculture and marine resource use, seafood trade, and development of fisheries and aquaculture activities; our international biennial conferences are forums for interaction among academics, industry members, government and non-governmental agency representatives to address marine resource related problems.

Aquaculture provides an increasingly significant proportion of the world's fish and marine products supply. As such, the vital issues surrounding the management and implementation of aquaculture projects, policy and regulatory questions about the use of marine and other water resources for the farming of fish and other marine products, the interaction between cultured and wild-caught products in the marketplace, and related topics are increasingly important themes of our conferences. This activity supports development of these themes for our fourteenth conference in Nha Trang, Vietnam. Further, IIFET used this support to plan and develop a program of prize and travel awards, and to leverage the grant by securing additional support to fund the prizes and travel. These awards provide incentives for developing country scientists to improve their awareness and use of economic methods and research programs related to aquaculture.

Accomplishments include holding broad discussions to develop aquaculture conference themes. The first call for conference participation was then issued and distributed online, in print, and by email. The conference was entitled "Achieving a Sustainable Future: Managing **Aquaculture**, Fishing, Trade and Development" in order to highlight the importance of aquaculture in Vietnam, in Asia, and in the conference. Additional sources of support for developing country participants who will make presentations on aquaculture economics have been identified, and will fund an Aquaculture Best Student Paper Prize, travel support for the prizewinner, and also provide travel support for at least two professional (non-student) participants. A plan is in place for solicitation of award applications, review and selection of winners, based on suggestions solicited from previous committee members of ways to improve the process. A review committee has been selected. Information about the awards has been circulated in various media, through electronic mail lists, websites, and in print.

INTRODUCTION

Activity History and Vision

Because aquaculture provides an increasingly significant proportion of the world's fish and marine products supply, the vital issues surrounding the management and implementation of aquaculture projects, policy and regulatory questions about the use of marine and other water resources for the farming of fish and other marine products, the interaction between cultured and

wild-caught products in the marketplace, and related topics are increasingly important themes of IIFET conferences. This activity was designed to support the development of aquaculture-related themes within the conference program.

Of equal importance is improving the potential for participation in our conferences by both students and professionals working on the important issues surrounding aquaculture economics in developing countries. Frequently, developing country scientists are unable to participate due to lack of support resources and networks. ACRSP provided support for three or more developing country scientists in IIFET Conferences in 2000, 2004, and 2006. This activity supports similar participation in the IIFET 2008 Vietnam conference, enabling 3 or more conference participants working on important issues related to conference themes, who would not otherwise be able to attend, to present their high-quality research for the mutual benefit of the funded participants and others present at the conference.

In the longer term, continuing to build on the conference participation made possible by past ACRSP support encourages and facilitates the continuation and development of aquaculture economic research and training in the developing world.

OBJECTIVES

The objectives of this activity included:

- To strengthen and develop the application of economic analysis to global aquaculture problems and issues surrounding farm management, aquaculture sector development, and marketing, by enabling and facilitating peer scientific exchange
- To strengthen the development and coverage of aquaculture topics at the IIFET 2008 Conference in Nha Trang, Vietnam
- To support participation by developing country scientists who lack the resources to travel to the conference, enabling mutual benefit from peer interaction on research and extension methods
- To develop networks to support these scientists, and others interested in aquaculture economics and related social science applications, in the future

METHODS AND MATERIALS

This activity supported interactions among IIFET's Executive Committee, the Conference Organizers at Nha Trang University, IIFET's Executive Director, a committee of aquaculture economics experts, and others, to develop the conference themes and title. Most of these discussions took place between February and September 2007, and were carried out by email or telephone.

Also supported was the development of the first call for abstracts and special sessions, to inform IIFET members and also those in a variety of aquaculture and fisheries organizations, government agencies, and academic research and education institutions about the conference, and to encourage their participation. Development of the information included in the call was done primarily by email; the call itself was distributed by email, website, and in print. Distribution will continue at a variety of conferences and events.

A panel of aquaculture economics experts was assembled (electronically) and polled for their review and ideas about the best way to implement the proposed set of two professional travel awards, and one best student paper prize. Their comments were integrated into the award and prize plan.

The IIFET Executive Director was supported by ACRSP to participate in the Asian Pacific Aquaculture 2007 conference held in Hanoi, Vietnam in August 2008. In conjunction with this visit she was able to meet in person with conference organizers. This trip enabled the planners to

carry out detailed, face to face discussions on a variety of programmatic and logistical issues, including the aquaculture prize program. In addition, we were able to recruit many new aquaculture contacts for the IIFET conference, by distribution of printed materials, announcements during sessions, and in-person networking. Contacts were made which will enable IIFET to work with other ACRSP/ Aquafish researchers to improve its offerings at future conferences in the area of integrating economic aspects into aquaculture research. Participation in the technical aquaculture sessions also familiarized the IIFET Executive Director with ways in which economics might be usefully integrated into this type of research, and vice versa.

RESULTS

Conference Title and Theme Development

After extensive discussion among a wide variety of partners, officers, and organizers, the title chosen for the IIFET 2008 Vietnam conference is: **Achieving a Sustainable Future: Managing Aquaculture, Fishing, Trade and Development**. The presence of the word “aquaculture” first in the list of topics is a direct result of the priority placed on this topic by IIFET’s President and the organizers themselves, the importance of this topic specifically for Vietnam and Asia, and also the support provided by ACRSP.

In addition, aquaculture was selected as one of the six main themes of the conference.

Within the aquaculture theme, the following potential session titles were listed:

Sustainable Aquaculture Production and Development

Aquaculture Sector Management and Regulation

Export Issues and Legal Challenges

Aquaculture and Its Contribution to Livelihoods

Aquaculture and Fisheries Interactions

However, aquaculture topics will not be limited to the above-listed proposed session titles. Individuals are encouraged to submit individual abstracts, posters, or entire special organized sessions, on additional topics of particular interest to them. Additional regular and special conference sessions will be generated from submitted abstracts which may not fall under any of the above-listed proposed session titles.

The call for abstracts, listing the conference title, themes and proposed session titles, is available at <http://oregonstate.edu/dept/IIFET/iifet2008.html>. The conference website, with more detail, is located at <http://www.ntu.edu.vn/iifet2008/>. (This site contains a great detail of information, and is still underdevelopment; additional information will be posted as it is developed.)

Prize and Award Plan

Three awards will be given, for a total value of approximately \$6,000.

3.2.1 Aquaculture Best Student Paper Prize: A prize of \$500 will be awarded to the author of the best student paper on an aquaculture economics topic. Honorable mentions may also be offered if appropriate. Students must first submit and have an abstract accepted by the conference scientific committee. Then, they must submit their completed paper, and an attestation of student status, by April 20, 2008, to the Executive Director of IIFET. Submissions will be distributed to a panel of three experts coordinated by the Executive Director. The experts will use standard journal article review criteria to select the paper which makes the most significant contribution in the application of economic analysis to an aquaculture-related topic. Contestants will be informed of results after May 20. The prize will be awarded during a ceremony at the IIFET 2008 Vietnam conference.

The winner of the Aquaculture Best Student Paper prize will also be afforded partial travel support by the IIFET Secretariat, worth up to \$2000 US. This support can be used to cover the student’s air tickets and/or lodging (expenses over the \$2000 amount will have to be covered by the prizewinner). Further, free conference registration will be provided by the Conference Organizer (Nha Trang University.)

Two (or more) professional travel awards will also be granted, of up to \$1800 US each. Applicants for these awards will also be required to submit materials by April 20, 2008. Application materials in this case will be comprised of an extended version of the short abstract which applicants must have had accepted by the conference scientific committee during either the early or regular abstract submission process. In addition to submitting an extended abstract of up to two pages in length, applicants will need to submit a letter describing what kind of support they will require, and what additional sources of support they will be using to support their travel.

The same panel of experts will evaluate and score the extended abstracts by May 20, 2008. The evaluations and scores will be provided to the Executive Director, who will prioritize them taking into account the quality of the submission, as well as regional and gender balance, while maximizing the number of participants who are assisted. The ability to leverage funds will be an attractive component of a candidate's application.

The Executive Director will inform the panel of her selections and then inform the winners as soon as possible after May 20, 2008. Any air tickets which are to be provided will be purchased by the IIFET Secretariat through Oregon State University. Any lodging expenses will be paid onsite by the Executive Director.

All recipients of aquaculture prizes will be required to submit a brief report describing their experience and providing details of any benefits which may accrue, in terms of professional exposure, networking, contacts of potential future use in their research programs or career development, etc. These reports will be provided to ACRSP.

The financial support for these awards was identified as a direct result of the support provided by this planning project. The \$6000 needed to support the awards was generated from several sources, including conference revenues, other revenue, and private donations.

USAID and ACRSP will be acknowledged in conference materials as a conference sponsor. Support for this planning project will be acknowledged during the conference in public announcements, including during the awards ceremony, and also be mentioned in the conference proceedings, which will be prepared after the conference.

Dissemination

The conference call for abstracts has been disseminated through the conference website, mentioned above. In addition some 5000 printed brochures have been or will be distributed at a variety of aquaculture and fisheries conferences, meetings, or through mailing lists. The call has also been distributed through many electronic lists, including lists pertaining to IIFET, the North American Association of Fisheries Economists (NAAFE), the European Association of Fisheries Economists (EAFE), Fishfolk, Seafood, Resecon, selected participants in the Asian Pacific Aquaculture 2007 conference, the IIFET conference distribution list, the Asian Fisheries Society, the International Association of Aquaculture Economics and Management, the Australian Marine Science Association, ACRSP, and a variety of others.

DISCUSSION

Ideas for future collaboration: the potential for expansion of the use of economics in aquaculture

At the Asian Pacific Aquaculture 2007 conference, the Executive Director had the very useful experience of observing a wide variety of technical presentations related to aquaculture production, as well as several related to marketing, consumer behavior, and policy. The huge potential scope for inclusion of both basic and more complex economic analysis emerged very clearly. Expanded content in farm level analysis, perspectives on costs and benefits of diverse regulatory and policy frameworks, and an in-depth understanding of markets and market channels are among the many areas in which economics might offer perspectives of value to aquaculture scientists. The Executive Director was able to discuss this with other conference

participants, and begin to develop networks for more collaboration between aquaculture scientists and aquaculture economists at future IIFET conferences.

CONCLUSIONS

For the fourth time, IIFET, its members, and others involved in the economics of aquaculture benefited from ACRSP support in the development of a plan to offer prizes and awards to those broadening the scope and coverage of our conference in the area of aquaculture. In this case, funds were spent on the planning process, but were leveraged to provide support for student and professional awards.

1. Anticipated Benefits

1.1 Aquaculture economics graduate students and their institutions

Prizes given to graduate students are beneficial to a degree disproportionate to their size. That is, it is not the amount of money which is offered, but the international recognition which a prize brings to them and to their institutions which determines the real value of the award. 1 or more graduate students and their institutions will benefit.

1.2 Aquaculture economists

The 2 or more who will be funded to participate in the conference will receive benefits including the opportunity to participate in an international conference, meet and interact with their peers from around the world, exchange views, information, and experiences on analytical techniques and methods, and present their work for constructive review by senior and world-renowned economists. In addition, the other 350+ conference participants will receive the benefit of the increased breadth of coverage in terms of numbers of countries represented and variety of analytical methods applied to an equal variety of problems and situations. The resulting publication of their results in both the conference proceedings, and in peer-reviewed journal literature outside of the conference, will extend the results to an even broader group. 2 or more conference participants will benefit directly, 350+ conference participants will benefit indirectly.

1.3 “Downstream” Beneficiaries

Benefits will be experienced by aquaculture practitioners in the countries where the researchers and managers participating in the IIFET conference work. Past papers presented have, for example, applied and developed economic techniques to evaluate the profitability, efficiency, and yield of aquaculture farms, assessed the effectiveness of traditional vs. modern production methods, evaluated the economic potential of the culture of new species, and suggested new marketing strategies for rural enterprises. All of this information, properly extended to rural populations, provides aquaculture farmers with information and techniques they need to improve their operations. An unknown number of aquaculture managers, extension agents, and practitioners benefit from the peer review, improvement, and use of the research presented.

1.4 ACRSP Management Entity

USAID and ACRSP receive benefits of improved visibility and public perception as a result of acknowledgement of ACRSP support for the IIFET conference and program.

ACKNOWLEDGMENTS

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**SPECIAL SESSIONS, TRAVEL AND POSTER AWARDS AT 2007 WORLD AQUACULTURE CONFERENCE,
SITE DESCRIPTIONS UPDATE**

Twelfth Work Plan, Applied Technology & Extension Methods 18 (12 ATE18)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

An Aquaculture CRSP session was organized and conducted at the US Aquaculture meetings in San Antonio TX in February 2007. In addition, funds were used to support travel and participation for six host country scientists and nine graduate students to attend the meeting. The session was well attended and included a full compliment of presentations of ACRSPsponsored research. The travel awards were determined on merit; depending on contribution to the research, quality of the abstract, participation in earlier ACRSPsponsored research and quality of the Power Point presentation developed for the conference.

A second aspect of this project was a series of awards for student posters presented at the same abovementioned conference. Three awards, cash plus certificates, were presented to the top three student posters. The posters were judged on scientific quality, contribution to the core ACRSPprinciple of sustainable aquaculture practices, and appearance and use of graphics.

The third aspect of the project was an updating of site descriptions for the various ACRSPprojects. Dr. Remedios Bolivar coordinated the collection and submission of the reports to the Home office for inclusion in final report.

The present project, 12ATE18, has been successful by improving recognition of the quantity and quality of research supported by the A CRSP. Much of the industry recognized and appreciated work done by many leading aquaculture scientists but had been unaware that the ACRSPwas a primary sponsor. By organizing these specific sessions and awards, the contributions of the ACRSPand US-AID sponsorship have been much more widely recognized.

INTRODUCTION

The Aquaculture CRSP has a long history of supporting travel to WAS conferences where research results were presented. However, recognition of the ACRSPas a funding and support entity were lacking due to the diffuse presentations across many disciplines within aquaculture. By organizing specific sessions for presentation of ACRSPresults the recognition of the ACRSPwas increased by an order of magnitude. Further, by also providing travel support and recognizing student posters with awards, the scope of ACRSP contributions was further magnified.

RESULTS

Pre-Conference Professional Travel Awards – World Aquaculture Society, San Antonio

The Aquaculture CRSP provided numerous pre-conference travel awards to the San Antonio

World Aquaculture Society conference, (Feb 2007). These awards were awarded to individuals based upon the following criteria:

1. Providing a presentation during the conference related to past or present Aquaculture CRSP research,
2. Scientific merit based upon submitted abstract,
3. Demonstrated financial need and matching leverage funds
4. Regional distribution

Awardees for the 2007 Pre-Conference Professional Travel Awards included:

Maria Celia Portella, Sao Paulo State University, Brazil
 Weimin Wang, Huazhong Agricultural University, China
 Yang Yi, Asian Institute of Technology, Thailand
 Steve Amisah, Kwame Nkrumah University, Ghana
 Suyapa de Meyer, Zamarono University, Honduras
 Remedios Bolivar, Central Luzon State University, Philippines

Pre-Conference Student Travel Awards

– World Aquaculture Society, San Antonio

Gustavo Rodriguez, Oregon State University
 Pablo Gonzalez Alanis, Autonomous University of Tamaulipas, Mexico
 Jason Licamele, University of Arizona
 Desale Zerai, University of Arizona
 Vicki S. Schwan, University of Michigan
 Cao Ling, Huazhong Agricultural University, China
 Rosa Perez, Universidad Juarez Autonoma de Tabasco, Mexico
 Milciades De La Cruz-Rodriguez, Universidad Juarez Autonoma de Tabasco, Mexico
 Moises Franco-Merchant, IT Boca, Veracruz, Mexico

Student Poster Awards:

The Aquaculture CRSP sponsored three student poster awards. One first place and two runner-up awards were given to those posters judged as the best representatives of the broad research and development theme “to advance sustainable aquaculture.” All posters submitted by students were considered and judging was conducted using accepted Aquaculture CRSP guidelines. Specific judging criteria focused on value of the contribution to sustainable aquaculture development, technical quality of the study and level of involvement required, presentation and use of graphics, and overall applicability and benefits of the results.

Aquaculture CRSP awards were presented to the winning students during the Student Reception. The highest judged student posters at the World Aquaculture Society 2007 meeting were as follows:

First Place Poster Presentation (\$400) - Heidi Lewis (Southern Illinois University - Carbondale) for the poster "Differential Effects of Dietary Lipid Source on Biochemical Composition of Striped Bass *Morone saxatilis* Gametes"

Second Place Poster (\$200) - Guillaume Salze for " Impacts of Dietary Mannan Oligosaccharides and Yeast Cell Cytoplasm Extracts on Gene Expression in Zebrafish *Danio rerio*"

Second Place Poster (\$200) - Mario Hernández-Acosta for "Growth and Development of Nile Tilapia *Oreochromis niloticus* Fingerlings, Fed with Different Diets Supplemented with Soapbark Tree Extract"

Site Descriptions

Dr. Bolivar contacted past and present host country PI's and US collaborators to obtain updated site descriptions. She also obtained new descriptions for some of the added sites including Ujong Batee in Aceh, Indonesia. The reports were submitted to Oregon State for inclusion in the ACRSP Final Report.

DISCUSSION AND CONCLUSIONS

The project has successfully brought six scientists from host countries and nine students (seven from developing countries) to participate in the 2007 World Aquaculture meetings. This has provided a direct boost to their professional careers and helped to disseminate information from the professional presentations at the WAS back to the host countries.

The students' awards provided very good publicity to the hard work of many deserving students and their education programs. Further, they provided a centerpiece to the student functions at the meetings and served to raise the profile of the student posters.

The ACRSP sessions themselves served to bring together ACRSP sponsored research that in the past had been delivered across many sessions. The higher visibility of the ACRSP has been important recognition of the scope of ACRSP work and the support provided by the US AID.

ANTICIPATED BENEFITS

Some of the immediate benefits from the pre-conference awards were the rapid dissemination of new information presented by the participants both in the oral and social portions of the WAS. On a longer term basis, the knowledge gathered at the WAS meetings that returned with the participant to the host country is an important aspect of improving capacity.

There are several benefits for the students who participated and even more to those who receive the poster awards. The cash awards are very helpful to the students, who are usually operating with limited means. However, the professional recognition is the real benefit. This achievement is an important line on a CV or resume that will help them to move to new positions and jobs in their careers.

Finally, a true benefit for the ACRSP is the publicity and recognition that the ACRSP garners as a key contributor to research in the aquaculture field. The awards and special sessions served to raise the profile of the ACRSP by focusing the array of ACRSP work.

ACKNOWLEDGMENTS

A large number of senior ACRSP scientists and administrators served as judges for the student poster awards. This entailed many hours of carefully reading a large number of posters during a very busy time when there were competing demand on their time. Judging is under-recognized as an important professional contribution that carries little prestige but is critical to the success of scientific programs.

Several senior ACRSP scientists and administrators also served to judge the pre-conference awards. Again their contributions are critical to the program and under-recognized.

LITERATURE CITED

Numerous newsletters and websites reported on the awards. There were no peer reviewed articles generated.

EVALUATION AND IMPROVEMENT OF TILAPIA FINGERLING PRODUCTION AND AVAILABILITY IN HONDURAS

*Twelfth Work Plan, Seedstock Development & Availability 1 (12SDA1)
Final Report*

Published as Submitted by Contributing Authors

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ABSTRACT

We studied reproduction of Nile and red tilapia on our station in Zamorano, Honduras. The estimated costs for producing Nile and red tilapia fry (≤ 12 mm) in a concrete tank and in an earthen pond were calculated. Results indicate that Nile fish produced 85% more fry ($P \leq 0.05$) than the red tilapia in the earthen pond compartments, and 65% more fry when stocked in the concrete tanks. Taking into account the significantly greater numbers of Nile fry produced both in the concrete tanks and in the earthen ponds, and their better survival rate during sex reversal, the costs for reproducing the Nile fish is lower than for the red tilapia. Under Zamorano conditions, the economic benefits are much higher for reproducing and selling Nile fingerlings.

We have trained more than 500 people (direct beneficiaries) in 11 events held in eight different countries in Latin American and the Caribbean. A draft of the training manual in Spanish on tilapia reproduction and fry rearing techniques has been completed and is in the validation, final editing and formatting phase, after which it will be ready for printing.

INTRODUCTION

In the study "Improvement of tilapia fingerling production and availability in Honduras, seed stock development and availability" done from August 2004 to July 2005 (CRSP, 2005), a survey of 22 tilapia fingerling producers was conducted to evaluate production in Honduras and examine the factors that influence the way farmers produce and distribute fingerlings.

The study examined three indicators to evaluate fingerling quality (uniformity of size, body color and percent of male gender fish) among fish from each producer. The results of the study showed that most of the batches evaluated fell below the 90% level of uniformity of size, color and percent male fish. The high level of variability among the lots of fish evaluated was related to not adequately grading/sizing fry prior to sex reversal, and using inadequate dosages of the hormone and shortening the treatment period.

Some fingerling producers do not properly count their fish and have problems calculating the right amount of feed to offer. Other farmers do not select brood fish and their fingerlings have a variety of body color patterns.

Farmers' expressed a need for more training opportunities on tilapia reproduction and rearing fingerlings, grow-out of tilapia, and record keeping and determination of their on-farm production costs (Triminio 2005).

In order to address some of these needs, the project:
Evaluated production costs and returns for producing tilapia fingerlings in Honduras

Trained NGO extension agents and fish farmers from several Latin American countries on the techniques of tilapia reproduction, sex-reversal and distribution of fingerlings
Is producing training materials in Spanish on the topics of tilapia reproduction, fry rearing and distribution, for dissemination to local farmers, NGO extension agents and other persons interested in tilapia culture.

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Triminio Meyer S. 2005. Tilapia Fingerling Production in Honduras. M.Sc.Thesis, Agricultural economics and rural sociology Department. Auburn University. Alabama.

Objective 1. Investigation/Study

Study Title: Comparison of Nile and Red Tilapia Reproduction

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ABSTRACT

Nile tilapia produced 85% and 65% more fry (≤ 12 mm) than red tilapia in a concrete tank (15 m²) and in an earthen pond (100 m²), respectively ($P \leq 0.05$). Due to the lower mortality of the adult fish and greater numbers of fry harvested, the production costs for Nile tilapia fry (USD 0.001 each) were much less than for the red fry (USD 0.003 each).

The average production cost for a sex reversed fingerling was USD 0.005 and 0.009 for the Nile and red fish, respectively. The difference in cost is due in large part to the difference in the observed survival rates between Nile (85.1%) and red fry (58.0%) during the 28-day hormone treatment period.

Taking into account the significantly greater numbers of Nile fry produced both in the concrete tanks and in the earthen ponds, and their better survival rate during sex reversal, the costs for reproducing the Nile fish is lower than for the red tilapia. Under market conditions for Zamorano, the economic benefits are much higher for producing and distributing Nile fingerlings compared to red fish.

INTRODUCTION

Tilapia was introduced to Central America in 1954 by FAO specialists (Meyer 1989). Today the commercial culture of tilapia is important in several regional countries. Most fish farmers in the region culture either the Nile or red varieties of tilapia (Aceituno *et al.* 1997; Tave *et al.* 1989). There are several important differences among these fish.

Both the Nile and red fish are considered resistant to pathogens and hardy. The Nile fish has a blue color. The red varieties of tilapia adapt easily to saline and brackish water and have growth rates similar to the Nile fish (Stickney 1986). For this study we compared the reproduction of Nile and Florida red tilapia on our station in Zamorano, Honduras.

MATERIALS AND METHODS

The trials were done in two 200 m² earthen ponds (20 x 10 x 1 m) and four 15 m³ concrete tanks (7.5 x 2.0 x 1.0 m). Each earthen pond was divided in half by installing fiber-glass window screening (1 mm) maintained and supported in a vertical position by wooden stakes. The screening was reinforced with 3 mm mesh Vexar™ plastic netting. Both netting materials were partially buried in the bottom mud of each pond and anchored by bricks placed at 50 cm intervals on each side of the barrier.

The concrete tanks were covered by predator netting (2.5 cm mesh). The water in each tank was continuously aerated by three 10 cm long fused silica diffusers connected to a blower (2.5 HP) via PVC pipe (2.5 cm diameter). The adult fish were fed at 3% of their biomass per day in the tanks and ponds with a floating pelleted diet.

Adult Nile and red tilapia were stocked into each of the four 100 m² pond compartments at 23.2 Kg biomass of females, and in the concrete tanks at 6.5 Kg of biomass of females. Male fish were stocked in both ponds and tanks at a 3 female:1 male ratio. The average weight of the adult females was in the range of 180 to 230g.

The 30-day long trial was repeated three times in the pond compartments (total of six repetitions). The trial in the concrete tanks was repeated twice, each time for 20 days (total of four repetitions). Adult fish were rested for a minimum of seven days between trials.

Water temperature and dissolved oxygen levels were monitored in the morning and afternoon hours of each day with an YSI model 55 meter. Free-swimming fry were captured from the 100 m² pond compartments using hand nets every other day. All fry were harvested and the concrete tanks drained on day 20 of each production cycle.

All captured fry were enumerated by visual comparison of populations. One-thousand fry were individually counted into a white plastic dish containing 2 L of water. Additional fry were added to a second identical dish until the populations appeared equal by visual comparison. This procedure was repeated and any remaining fry were counted individually.

The fry from all trails were then sex-reversed (60 mg of 17- α -methyl-testosterone/Kg of prepared feed) for 28 days (Popma and Green 1990) in 15 m³ concrete tanks (7.5 x 2.0 y 1.0 m) at a stocking density of 2000/m³. The 38% crude protein feed was offered to the fish in each tank four times daily.

RESULTS AND DISCUSSION

During the several repetitions of the experiment, the water temperatures at the Zamorano Aquaculture Station ranged from 23.8 to 31.5° C, and averaged 28.1° C in the ponds. Water temperature in the concrete tanks ranged from 24.6 to 30.0° C, with an average of 27.4° C.

Morning dissolved oxygen concentrations below 2.9 ppm were never detected in the water of the concrete tanks. Low dissolved oxygen levels (\leq 1.0 ppm) were detected in the ponds on several occasions. No dead adult fish were ever observed in the water of the ponds or tanks.

The Nile fish produced 85% more fry ($P \leq 0.05$) than the red tilapia in the earthen pond compartments, and 65% more fry when stocked in the concrete tanks (Tables 1 and 2).

The red tilapia is a hybrid containing genes from several species (Tave et al. 1989). This genetic diversity among the red fish may cause problems during pairing and courtship. The fry production per g of female biomass and per m² per day reported here (Tables 1 and 2) generally coincide or exceed the values compiled by Green et al. (1997) for fish reproduced in hapas, tanks or earthen ponds.

The final average weights from this study (Table 3) are similar to fry reared by El-Sayed (2002) and Meyer and Smitherman (1993). The difference in the average final weights for sex reversed Nile and red fingerlings is attributed to the difference in fingerling survival. The red fish were effectively reared at a lower density due to their higher mortality during the 28-day treatment period. Weight gain is inversely related to tilapia fry stocking density (El-Sayed 2002).

The adult red fish were injured and died more frequently than the Nile tilapia adults. The greatest mortality of red fish was observed during final harvest and draining of the earthen ponds where an average of 11% of the stocked fish died. No Nile adults died during the trials in the concrete tanks. The loss of Nile adults in the earthen ponds averaged 6% of the brood stock. When the ponds are drained some of the fish become stranded in the mud and covered with sediment, and suffer injuries that can lead to infection and death.

Labor costs were higher for managing the fish in ponds due to the greater number of adult fish stocked and harvest of a greater number of fry. A comparison of the estimated costs for producing Nile and red tilapia fry (≤ 12 mm) in a concrete tank and in an earthen pond is presented in Table 4. Due to the lower mortality of the adult fish and greater numbers of fry harvested, the production costs for Nile tilapia were much less than for the red fry.

The values in Tables 5 and 6 are based on the sex reversal of equal numbers of Nile and red fry stocked and sex reversed in a concrete tank. The difference in net income generated is due in large part to the difference in the observed survival rates between Nile (85.1%) and red fry (58.0%) during the 28-day treatment period.

Sex reversed red tilapia fingerlings generally are offered for sale at a higher price than similar Nile tilapia fingerlings (Tables 5 and 6) (Aceituno *et al.* 1997). Labor and feed costs were higher for the Nile fish due to their greater numbers at harvest and estimated additional time for handling and counting the fish. The feed for the fry is prepared by grinding and then passed thru a fine meshed sieve (0.01 mm). The feed contains 38% crude protein and 60 mg of hormone /Kg.

CONCLUSIONS

The production and sale of sex reversed tilapia fingerlings in Honduras is a profitable activity. The net income in USD from the production and sale of all-male Nile fingerlings was greater than income from red fry.

Taking into account the significantly greater numbers of Nile fry produced both in the concrete tanks and in the earthen ponds, and their better survival rate during sex reversal, the costs for reproducing the Nile fish is lower than for the red tilapia. Under market conditions for Zamorano, the economic benefits are much higher for producers using Nile tilapia.

ANTICIPATED BENEFITS

The results of this study have and will support the technical and economic information transferred to trainees during the courses promoted and supported by CRSP. The study results form an important part of the training manual on reproduction and rearing of tilapia fingerlings, being prepared as part of this CRSP supported work plan. It is intended that this information will reach a wider audience by posting it in the website www.acuacultura.org and its dissemination at professional meetings.

ACKNOWLEDGMENTS

This study was conducted under the economic support to the Aquaculture CRSP, WP12. We want to thank the staff of the Zamorano Aquaculture Station (Claudio Castillo, Franklin Martinez and Adonis Galindo) who supported all activities related to this study.

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Objective 2: Training Events/Activity

INTRODUCTION

In response to needs expressed by fish farmers, we organized several training events focusing on the biology and reproductive cycle of tilapia, proper handling of the fingerlings for hormone treatment, and packing and transporting of fingerlings. Table 8 shows that we have contributed to training 504 fish farmers, extension agents, governmental officials, students, and university staff, from eight countries in Latin America and the Caribbean: Honduras, El Salvador, Nicaragua, Guatemala, Mexico, Chile, Dominican Republic and Haiti.

Although our original work plan did not contemplate this amount of training events and trainees, this accomplishment was made possible due to the collaborative efforts between Zamorano and tilapia stake holders in Latin America. These collaborators have contributed a variety of resources (economic, logistical and organizational) to facilitate our efforts and offset our expenses.

The support of the ACRSP project has helped to strengthen Zamorano's institutional capacity and establish this university as an important source of information and knowledge on tilapia culture in Latin America.

During this period, we were invited to do several courses due to our hosts knowledge of previous CRSP events in Central America. Recently a Zamorano staff member from our Aquaculture Station (Claudio Castillo) participated in an the International Seminar on Aquaculture, San Jose, Costa Rica in April of 2006. Claudio is invited to instruct a course on tilapia culture to first-year students in the aquaculture program of the Catholic University of Temuco, Chile, in April of 2007.

During this period Suyapa Triminio Meyer finished her Master of Science degree at Auburn University (August 2005). The results of her thesis will published in the *Journal of Applied Aquaculture* in June 2007.

ANTICIPATED BENEFITS

More than 500 fish farmers, extension agents, students and interested individuals have directly benefited from our training events in eight countries. We have broadly disseminated useful information in Spanish on tilapia culture, reproduction and fingerling rearing and distribution in eight countries.

Many contacts were made and some alliances have been formed. Zamorano is now engaged in forming a network of Latin American and US universities for coordinating research on freshwater native finfish species. There is an increased interest between several universities and research institutions to begin student and faculty exchanges in the area of aquaculture. Some topics for further research and development have been uncovered during these activities for future students and for the benefit of the farmers of Latin America.

ACKNOWLEDGMENTS

This activity was conducted with the economic support of ACRSP under the WP12. We thank all the institutions, organizations and individuals who collaborated in the eight countries where the training events took place. These include: Centro de Estudios de Mar y Acuicultura (CEMA), Universidad de San Carlos, Guatemala; University Benito Juarez, Tabasco, Mexico; Universidad Católica del Trópico Seco (UCATSE), Estelí, Nicaragua; Professor Javier Quevedo from Universidad Católica de Temuco, Chile; Instituto Dominicano de Investigación en Agricultura y Forestales (IDIAF) and the Kellogg Foundation in Santiago, Dominican Republic; the Superior Institute for Agriculture (ISA), Alumni Association of Panamerican Agriculture School for Dominican Republic and Alumni Association of Panamerican Agriculture School for Haiti.

Objective 3. Developing Training Materials/Activity

INTRODUCTION

A draft text (approximately 20 pages) for the manual on tilapia reproduction and fry production techniques in Spanish has been prepared along with approximately 40 photographs to illustrate important points and topics.

The manual includes the following segments or topics: preface, introduction, general description of tilapia, limits to successful tilapia culture, description of the Nile, red, white and Java tilapia, optimum conditions for tilapia reproduction, description of the tilapia life cycle, courtship and mating, managing cultures for rearing fry, suggestions for selection of brood stock, stocking density for brood stock in reproduction units, natural incubation of fertile eggs and embryos, managing reproduction units, harvesting fry from reproduction units, artificial incubation, sorting fry by size, techniques for counting tilapia fry, the sex reversal procedure, preparing feed with methyl testosterone, feeding fry during sex reversal, transporting fingerlings, estimated production costs for reproduction and rearing of tilapia fingerlings, glossary of terms, and list of references and useful bibliography.

We have also developed several Power Point presentations that have been used in our recent training events based on our ACRSP funded activities in Honduras and other locations. The Power Point files include the topics of tilapia reproduction, sex reversal techniques, transporting fish and fingerling production costs, derived from CRSP supported work in Honduras.

The draft copy of the manual has been reviewed by a CRSP researcher and also by an extension agent from Zamorano. Pending are the revisions by a professional editor, a panel of additional extension agents and fish farmers, and another CRSP researcher. Upon completion of this review

process, the manual will be sent to the printer, planning to have the final product by the end of March.

ANTICIPATED BENEFITS

These materials have been widely used in our training events to instruct fish farmers and NGO and government extension agents in the fundamentals of tilapia brood-stock selection and management techniques for reproduction, and fingerling production, cost and distribution. We consider that at least 300 farmers have directly benefited from this information.

ACKNOWLEDGMENTS

We thank the persons that have contributed with their comments, photographs and suggestions concerning content of the reproduction manual. We thank several short course participants who suggested modifications and identified missing topics from the draft manual. This study was conducted with funding of the Aquaculture CRSP WP12.

Table 8. Summary of training events conducted by ACRSP Honduras team during WP12 in Latin America.

Description of short course and location:	Dates (duration)	Number of participants	Target group	Collaborators:	Topics included:
Title: Fingerling Production Zamorano, Honduras	Dec 9-12, 2003 (4 days)	11	Fingerling Producers and NGO agents		Tilapia biology, reproduction, sex reversal, record keeping, fingerling transportation. These farmers participated in the study and were already producers.
Title: Fingerling Production Zamorano, Honduras	July 28-31, 2004 (4 days)	24	Fingerling and tilapia producers, government and NGOs Agents		Tilapia biology, reproduction, sex reversal, record keeping, fingerling transportation. These new producers
Title: Culture of tilapia. Universidad de San Carlos, Ciudad de Guatemala, Guatemala	March 10-12, 2005 (3 days)	55	Farmers, Students and government and NGOs agents	Centro de estudios de Mar y Acuicultura (CEMA), Universidad de San Carlos.	Overview of CRSP activities and research results; tilapia culture in Central America; pond construction; biology of tilapia; nutrition & feeding; fertilization; water quality; reproduction; fry production; common problems; ACRSP supported web site; field visit to projects.
Presentation: Fingerling production in Honduras University Benito Juarez, Tabasco, Mexico	Oct 3, 2005 (one day)	30	Students, farmers and staff	University Benito Juarez, Tabasco, Mexico	Presentation of results and recommendation of the study of tilapia Fingerling Production in Honduras. One hour presentation by Suyapa Meyer
We organize, contact and invite to the course “Safe Use of Hormones” offered in San Pedro Sula, Honduras by our colleagues of the University Benito Juarez of Tabasco, Mexico	October 13-14, 2005 (2 days)	70	Farmers, government officials and extension agents	University Benito Juarez of Tabasco, Government of Honduras, Caritas of Honduras	Hormones for masculinization, Filter of effluents of fingerling production.
Presentation: Honduras’ Tilapia Marketing Experience Jornada Acuicola, Guatemala City, Guatemala	November 04, 2005	100	University staff & students, farmers, investors, extension agents, and government officials	University of san carlos de Guatemala and the Veterinarians Association of Guatemala	Tilapia Marketing, prices, product presentations, venues, One hour presentation at this event in Guatemala by Suyapa Meyer
Course Biology and culture of tilapia, Marketing and costs.	November 9-11, 2005 (3 days)	95	Students, farmers, investors, extension agents and government officials	Universidad Católica del Trópico Seco (UCATSE), Estelí, Nicaragua Aquaculture Station	Overview of CRSP activities and research results; tilapia culture in Central America; pond construction; biology of tilapia; nutrition & feeding; fertilization; marketing tilapia in CA; water quality; tilapia reproduction; fry production; common problems; production costs projects.

Table 8 (continued)

Course: Tilapia Culture and Marketing, Rural Aquaculture in Central America Universidad Católica de Temuco, Chile	November 2005 (3 days)	60	Students and staff of UCT, Chile	Universidad Católica de Temuco, Chile	Overview of CRSP activities and research results; tilapia culture in Central America; pond construction; biology of tilapia; nutrition & feeding; fertilization; marketing tilapia in CA; water quality; tilapia reproduction; fry production; common problems; production costs for tilapia culture; ACRSP supported web site; field visit to projects. An over view of rural aquaculture in Honduras and domestic and export markets for tilapia
Title: Curso sobre la biología y cultivo de tilapia. Costs and marketing Superior Institute for Agriculture (ISA), Santiago de los Caballeros, Dominican Republic	April 7-16 2006 (2 days)	34	Students, Farmers, NGOs and government agents, University staff 16 participants from Hati and 18 from Dominican Republic	Instituto Dominicano de Investigación en Agricultura y Forestales” (IDIAF) Kellogg Foundation in Santiago, DR, Superior Institute for Agriculture (ISA) Alumni Association of Panamerican Agriculture School Dominicana	Overview of CRSP activities and research results; tilapia culture in Central America; fish culture in the DR; pond construction; biology of tilapia; nutrition & feeding; fertilization; marketing tilapia in CA; water quality; tilapia reproduction; fry production; common problems; production costs for tilapia culture; ACRSP supported web site; field visit to projects.
Taller - Práctico de Técnicas para el establecimiento y manejo del cultivo de peces (tilapia) Zamorano, Honduras	July 4-7, 2006 (4 days)	12	Farmers, feed producers and Bank agents	Course was sponsored by ACRSP and Zamorano	Overview of CRSP activities and research results; tilapia culture in Central America; pond construction; biology of tilapia; nutrition & feeding; fertilization; marketing tilapia in CA; water quality; tilapia reproduction; fry production; common problems; ACRSP supported web site; field visit to projects.
Taller - Práctico de Técnicas para el establecimiento y manejo del cultivo de peces (tilapia). Marketing and costs Zamorano, Honduras	September 22-23, 2006 (2 days)	13	Farmers	Course was sponsored by ACRSP and Zamorano.	Overview of CRSP activities and research results; tilapia culture in Central America; pond construction; biology of tilapia; nutrition & feeding; fertilization; marketing tilapia in CA; cost determination, water quality; tilapia reproduction; fry production; common problems; ACRSP supported web site; field visit to projects.
Total trainees		504			

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

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

Final Report

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ABSTRACT

The African catfish, *Clarias gariepinus*, is endemic to Kenya. It is considered to have excellent flavor and is therefore popular as a food fish. With a growing interest in aquaculture, some fish farmers are turning to the production of catfish fingerlings to sell for stocking in earthen ponds as well as for baitfish in the Lake Victoria Nile perch long-line fishery. Although spawning of *Clarias* is not a major problem, sufficient quantities of fingerlings are not being produced, due to low and highly variable rates of survival. Survival rates range from 1 to 50% in ponds, with a rate of 25% (egg to 5-gram fingerling) considered good. For producers to meet the increasing demand for fingerlings, however, techniques must be found to significantly improve these survival rates.

The primary objective of the studies described here has therefore been to assess management strategies that might contribute to improved growth and survival of African catfish juveniles. Two studies were conducted by graduate students (MSc candidates) at Moi University, Eldoret, Kenya, in 2005 and 2006. In one study, catfish larvae were stocked into eighteen 30-L glass aquaria in the hatchery, where they were offered three diet sequences and reared under two light regimes for a period of 30 days. The diet sequences tested were an *Artemia*-chick mash sequence, a rotifer-chick mash sequence, and chick mash only. Nine aquaria were illuminated and nine were darkened. Offering live feeds (*Artemia* or rotifers) prior to switching to a prepared feed (chick mash) led to better growth and survival than rearing larvae on the prepared feed only. Larvae reared in darkness had better growth and survival rates than those reared in illuminated aquaria.

The second study consisted of two separate experiments. In the first experiment, catfish larvae were reared in the hatchery for periods of 1, 5, 10, and 15 days prior to being stocked into hapas in ponds, where their culture was continued up to a total of 60 days (hatchery plus pond). Larvae reared for 10 days prior to the transfer showed the best growth and the second best overall survival. For the second experiment, all larvae were reared in the hatchery for 10 days and then transferred to hapas, where they were stocked at densities of 25, 50, 100, and 200 fish/m² and reared for 42 days. In this experiment, stocking fish at 25/m² resulted in both the most growth and the best survival among the treatments.

All field and statistical work has been completed and student theses have been submitted either to graduate committees or to the Graduate School.

The findings of this research will be applied to *C. gariepinus* fingerling production on government and private farms in Kenya. They will also be included in a new fish farming handbook being prepared under ACRSP sponsorship, providing farmers and extension workers with access to the latest information. Application of new techniques will ultimately result in increased supplies of *Clarias* fingerlings, and resulting increases in aquaculture and fishery production will contribute to greater fish consumption and thus to human health and welfare in the region.

INTRODUCTION

Efforts to grow fish in ponds in Kenya began in early 1920. However, rural fish farming dates back to 1940s when farmers in Central and Western Kenya started to construct fish ponds to culture Nile tilapia. In spite of several decades of fish culture, Kenya's aquaculture has not come far and remains a young industry, practiced mainly on a small scale using tilapia (*Oreochromis niloticus*) and catfish (*Clarias gariepinus*) and producing only about 1,000 metric tons annually.

Clarias gariepinus is probably the most widely distributed fish in Africa (Skelton 1993). It can endure very harsh conditions by using its accessory air breathing organ, is highly omnivorous, and grows quickly. The fish has high potential for aquaculture in this region. Research into the culture potential and the artificial propagation of catfish is reported to have begun in the 1970's. (DeKimpe and Micha 1974; Hogendoorn 1984).

Clarias are farmed in polyculture with Nile tilapia to control unwanted reproduction. They are also grown in monoculture as food fish. More recently, *Clarias* culture has gained in importance as a way of producing bait fish for the Lake Victoria Nile perch industry. The traditional supply of fingerlings is wild-caught fingerlings from Lake Victoria itself, but this supply is intermittent and seems to be related to the extent of water hyacinth rafts drifting in near-shore areas, with *Clarias* being numerous under the water hyacinth. Fishers sometimes use small-mesh beach seines and mosquito nets to catch fingerlings for bait, but beach seining is highly destructive of the spawning habitats of native cichlids and is illegal. Fishing with mosquito nets has also recently been banned by the government. Fishers find themselves in a difficult situation because they need the bait at an affordable price to be able to continue fishing.

Poorer fishermen have resorted to long-line fishing and their favorite bait is *Clarias* fingerlings. Desired bait size varies widely, ranging from 5 to 20 grams per fish. A quick survey of fishermen gave hugely varied numbers of fishers and number of hooks per fisher, but it seems that fishers bait from 100 to 1000 hooks per boat per day, and the demand in Kenya is between 5,000 and 50,000 *Clarias* fingerlings per day. At 300 fishing days per year, this equates to an annual demand of between 1.5 and 15 million fingerlings. At a reported selling price of 2 to 3 KSh per fingerling and an estimated production cost of about 0.1 KSh per fingerling (Veverica, personal communication, 2001), farm-based production could be a highly profitable business for fish farmers. Although recent thesis work by one of our students estimated that fingerling production costs would be just under KShs1.00, his investigation still suggested that producers could realize returns of 400% or more on their investments.

The African catfish, *Clarias gariepinus*, is endemic to the Lake Victoria region. It is popular with the communities living around the lake and a lot consider its taste as excellent. Like many other indigenous fish species tried in aquaculture, lack of adequate seed is a drawback to production of catfish. Spawning of *Clarias* is not a major problem, but sufficient quantities of fingerlings cannot be produced due to very low survival to fingerling size. Spawning success as reported by Karen Veverica (Personal Communication) has been quite good, but survival to fingerling size is variable, ranging from 1 to 50% in ponds, with a survival rate of 25% from egg to 5-gram fingerling considered good.

Work on increasing the survival of *Clarias* fry to the fingerling stage was begun under CRSP sponsorship through a series of experiments conducted at Moi University, Eldoret, Kenya, in 2002 and 2003 (Ngugi et al. 2004). That work included studies on suitable first feeds and appropriate

stocking densities for *Clarias* fry nursed indoors in 30-L glass aquaria, as well as studies on appropriate stocking densities and varied amounts of cover provided for fry reared in hapas in outdoor ponds. Results from the indoor studies suggested that near-pure cultures of rotifers produced in fertilized earthen ponds might successfully be used, in place of *Artemia*, to rear *Clarias* fry in tanks—although the growth of fry fed *Artemia* was better than that of fry fed rotifers, the difference was not statistically significant. On the other hand, survival of fry fed rotifers was higher than that of fry fed *Artemia*, although not significantly so. The density study indicated that the best stocking density, in terms of both growth and survival, was about 10 fry/L (tested densities were 5, 10, 20, and 30 fry/L). In the outdoor pond/hapa studies, better survival and growth of fry were achieved when the hapas were 100% covered with grasses, as opposed to when 0-, 30-, or 60-% covered. Of the hapa stocking densities tested (100, 200, and 400 fry/m²), the best appeared to be about 100 fry/m². Because this density was the lowest among those tested, further work on lower hapa stocking densities appears to be in order.

Results from the above experiments suggest that additional work should be done to further increase survivals in both indoor systems and outdoor ponds and hapas. Accordingly, this activity addressed how the length (duration) of the nursery rearing phase, stocking densities, alternative feeding strategies, and factors such as predation and cannibalism affect the growth and survival of *C. gariepinus* fry.

MATERIALS AND METHODS

The overall objective of this investigation was:

To assess management strategies that may contribute to improved growth and survival of African catfish (*Clarias gariepinus*) juveniles in the hatchery and in ponds.

More specifically the objectives were:

To determine the effects of three feeding regimes (rotifers, *Artemia*, and a commercial feed offered in different combinations and sequences) on the growth and survival of *Clarias gariepinus* larvae reared under two light regimes.

To assess the effect of varying stocking density and hatchery rearing duration on growth and survival rates of African catfish (*Clarias gariepinus*) larvae.

Strategies investigated included:

Varying the duration of the rearing phase and assess its effect on growth and survival of juvenile catfish reared in indoor aquaria and in hapas suspended in static ponds.

Offering live, freeze-dried, and formulated feeds to hatchery-reared larvae in different sequences, rather than offering them a single feed throughout rearing period

Varying the stocking densities of catfish juveniles reared in the hatchery and hapas suspended in static ponds

Two sets of experiments were selected from among the options listed in the proposal for this activity as well as under “objectives” above. One of these sets was undertaken by each of our master’s students, Ms. Victoria Boit and Mr. Stephen Njau, as part of their MSc programs in the Moi University (MU) Department of Fisheries and Aquatic Sciences. All of their research was conducted in the Department’s hatchery and ponds at the MU Fish Farm on the Chepkoilel Campus in Eldoret, Kenya between June 2005 and June 2006 (Figure 1). The work was supervised by CRSP PIs Drs. Charles Ngugi, Head of the MU Department of Fisheries and Aquatic Sciences, and Jim Bowman, of the Department of Fisheries and Wildlife at Oregon State University.

Victoria Boit chose to work on the issues of darkened vs. illuminated rearing conditions in combination with different feeding regimes for *Clarias* larvae reared in aquaria in the hatchery, whereas Stephen Njau investigated the effects of different hatchery rearing periods (number of days in the hatchery) and different stocking densities for fry subsequently transferred to hapas in ponds.

For Ms. Boit's work, catfish larvae were stocked into eighteen 30-L glass aquaria in the hatchery, where they were offered three diet sequences and reared under two light regimes for a period of 30 days. The diet sequences tested were an *Artemia*-chick mash sequence, a rotifer-chick mash sequence, and chick mash only. Nine aquaria were illuminated and nine were darkened. Mortality, food consumption, fish appearance, and behavior observations were made twice daily, as were dissolved oxygen, pH, and temperature. Total ammonia, nitrite-nitrogen, and nitrate-nitrogen were determined every five days, and a sample of 30 fish was measured for growth (length and weight) every five days. All growth and survival data were analyzed independently using one way Analysis of Variance (ANOVA).

Mr. Njau conducted two separate experiments. In the first experiment, catfish larvae were reared in 30-L aquaria in the hatchery for periods of 1, 5, 10, and 15 days prior to being stocked into hapas in a pond, where their rearing was continued up to a total (hatchery plus ponds) of 60 days. Aquaria were stocked at a density of 10 larvae/L. The larvae were initially fed with live rotifers and switched to a fine-powdered trout feed (36% crude protein) after two days. Dissolved oxygen, temperature and pH were measured twice daily, and total ammonia nitrogen (TAN) and nitrite nitrogen ($\text{NO}_2\text{-N}$) levels in were measured in each aquarium every 5 days.

For the second experiment, all larvae were reared in the hatchery for 10 days (the duration giving the best results in the first experiment) and then transferred to hapas, where they were stocked at densities of 25, 50, 100, and 200 fish/ m^2 and reared for an additional 32 days. Dissolved oxygen, temperature, pH, transparency, and nitrogen ($\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$) of pond water were measured every five days. Every six days a random sample of 20 fish was drawn from each hapa to determine length and weight.

The pond in which the hapas were placed was dried prior to filling, limed at a rate of 600 kg CaCO_3 /ha, and fertilized with urea at 16 kg N/ha, DAP at 4 kg P/ha, and chicken manure at 500 kg/ha seven days prior to stocking.

RESULTS

After 30 days, the average weight of fish fed in the sequence Rotifer-*Artemia*-chick mash was 41.25 ± 5.64 mg in illuminated aquaria and 45.42 ± 6.17 mg in darkened aquaria. Larvae fed in a rotifer-chick mash sequence attained average weights of 49.31 ± 5.85 mg and 57.22 ± 3.64 mg in illuminated and darkened aquaria respectively. Larvae fed only chick mash had average weights of 23.81 ± 2.76 mg in illuminated aquaria and 25.14 ± 2.71 mg in darkened aquaria. Similar trends were observed in length measurements taken at the end of the experiment as shown in Figure 2. Survival was higher among fish fed the rotifer-chick mash sequence than those fed the rotifer-*Artemia*-chick mash sequence and those fed chick mash only as shown in Table 1. In conclusion, Ms. Boit found that offering live feeds (*Artemia* or rotifers) prior to switching to a prepared feed (chick mash) led to better growth and survival than rearing larvae on the prepared feed only. Larvae reared in darkness had better growth and survival rates than those reared in illuminated aquaria. It is therefore recommended that catfish larvae be reared in darkened aquaria and fed first with live feed such as rotifers for the first ten days; thereafter, dry diets can be introduced to satisfy their energy demand.

In Mr. Njau's first experiment, larvae reared for 10 days prior to the transfer showed the best growth (significantly higher, $P < 0.05$) (Figure 3) and the second best overall survival to harvest, as compared with larvae reared in the hatchery for periods of 1, 5, and 15 days prior to being transferred. The highest survival rate was observed among larvae reared in the aquarium for only 5 days prior to transfer to hapas. This rate was significantly higher ($P < 0.05$) than that in all other treatments.

In the second experiment, stocking fish at 25/ m^2 resulted in the most growth among the treatments, as compared with fish stocked at the higher densities of 50, 100, and 200/ m^2 (Figure

4). The growth difference between fish stocked at 25/m² and 50/m² was not significantly different (P<0.05), but growth in these two treatments was significantly higher than in the higher density treatments (P<0.05). Specific growth rates (%) in the four treatments were not statistically different (P>0.05). Percent survival for fish stocked at densities of 25, 50, and 100/m² was not significantly different among treatments but was significantly higher than for fish stocked at 200/m² (P>0.05).

CONCLUSIONS

The results of Ms. Boit's work suggest that *C. gariepinus* larvae reared in the hatchery should be reared in darkness rather than under illuminated conditions, and that starting the larvae off on live feeds (for example, *Artemia* or rotifers) for 10-14 days and then shifting them over to prepared feeds will result in the best growth and survival.

The results of Mr. Njau's study indicate that for *C. gariepinus* larvae, a hatchery rearing period of 10 days prior to stocking in nursery ponds should be recommended. For transferring to hapas in nursery ponds, stocking densities below 200 larvae/m² do not have any advantage in relation to survival but larvae can be expected to exhibit significantly higher growth when stocked at or below 50 larvae/m².

ANTICIPATED BENEFITS

These research results have been adopted by Extension officers as well as fish farmers and are now being applied to the production of *C. gariepinus* fingerlings on both government and private farms. New information or technologies resulting from this research is being incorporated into training courses for extension workers and farmers producing *Clarias* fingerlings either at the FD and MU fish farms and at the farms of advanced *Clarias* producers. The catfish culture sections of the "New Guide to Fish Farming in Kenya," developed under an earlier CRSP investigation, have been updated to reflect the new information learned from this research. Increased supplies of *Clarias* fingerlings will provide Lake Victoria Nile perch fishers with a reliable source of bait. As a result, fishing pressure on immature *Clarias* in Lake Victoria should begin to diminish. Reduction in beach seining will reduce habitat destruction on native fishes in Lake Victoria. Net income to fishermen should increase as cultured baitfish become more available, provided costs are kept down through competition among bait producers. A steady supply of *Clarias* fingerlings will also help producers in areas where *Clarias* is gaining popularity as a cultured food fish. An increase in fish production realized through all these avenues should lead to greater supplies of fish in the markets and the consumption of more fish by the population, thus contributing to human health and welfare in the region.

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Table 1. Survival of fish fed three different diet sequences in light and dark aquaria for 30 days. Survival was higher among fish fed the Rotifer-Chick Mash sequence than those fed the Rotifer-*Artemia*-Chick Mash sequence and those fed chick mash only.

	LIGHT			DARK		
Sampling Dates (August)	Rotifer- <i>Artemia</i> -Chick Mash (%)	Rotifer-Chick Mash (%)	Chick Mash Only (%)	Rotifer- <i>Artemia</i> -Chick Mash (%)	Rotifer-Chick Mash (%)	Chick Mash Only (%)
5 th	100.00	99.56	99.22	99.89	100.00	99.56
10 th	99.78	98.44	96.22	99.56	99.11	97.78
15 th	95.78	97.78	90.56	84.00	98.11	76.11
20 th	90.00	96.56	63.44	76.56	96.22	47.22
25 th	81.67	89.89	38.78	64.33	91.11	42.33
30 th	74.00	84.67	31.22	51.00	87.00	40.89



Figure 1. Moi University Fish Farm, near the Chepkoilel Campus, Eldoret, Kenya. All research conducted under this investigation was conducted either at this farm or in the hatchery, which is located on the Chepkoilel Campus. The experimental pond used in Steven Njau's experiments is shown by the arrow.

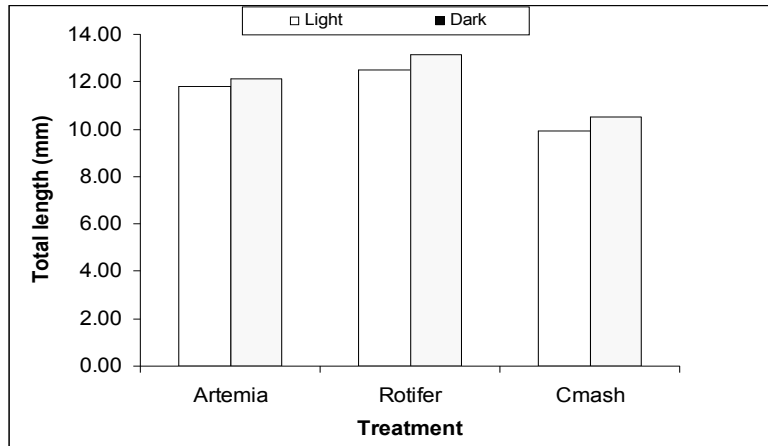


Figure 2. Final total lengths of fish fed three diet sequences in light and dark aquaria for 30 days. The final lengths of fish fed the Rotifer (Rotifer-Chick Mash) sequence were greater than those fed the *Artemia* (Rotifer-*Artemia*-Chick Mash) and C mash (Chick Mash Only) sequences.

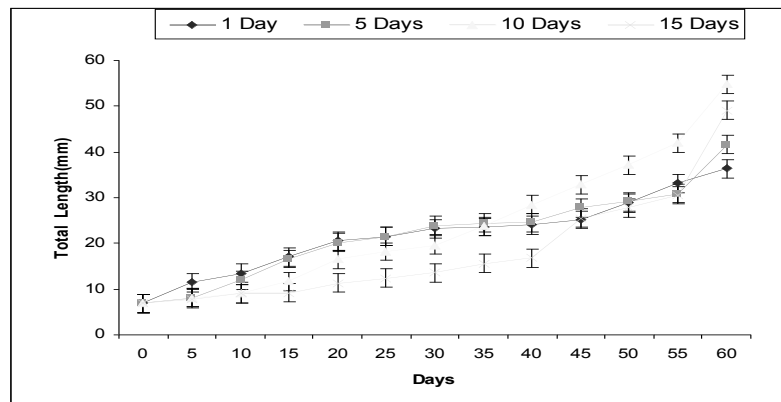


Figure 3. Growth of *Clarias gariepinus* fry reared for sixty days, beginning with initial aquarium rearing phases of 1-, 5-, 10-, and 15-day duration. Each data point represents mean length at age \pm Standard Deviation.

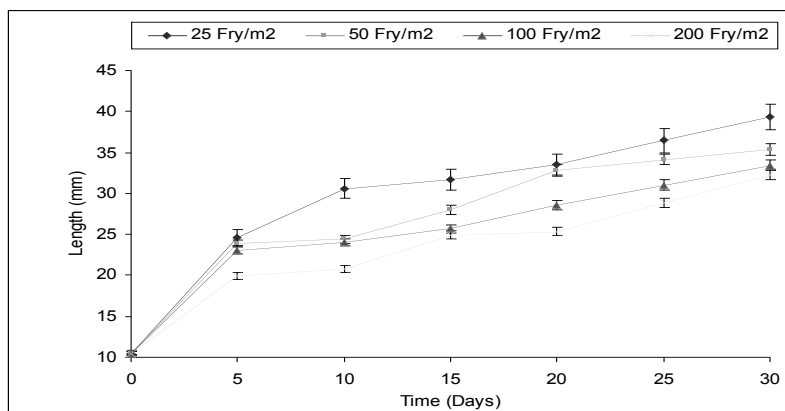


Figure 4. Growth in total length for *Clarias gariepinus* fry stocked in hapas at densities of 25, 50, 100, and 200 larvae/m² for a 42-day period. Each data point represents mean length at age \pm Standard Deviation. All fry had been reared in aquaria in the hatchery for ten days prior to stocking in the hapas.

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

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

Final Report

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ABSTRACT

Despite the establishment and long use of tilapia culture as a major economic activity and as a high-quality source of food, the emergence of this activity from a technical standpoint has been minimal. In Latin America, broodstock and seed supply have been identified as one of the major constraints to production increases. Inadequate availability and quality of fry and broodstock is considered a research priority. In Mexico, there has been little effort given to the conservation and genetic selection of tilapia. This is despite the fact that these fish were introduced over 35 years ago, resulting in benefits related to food production. Genetic improvement in aquaculture offers an opportunity to increase production, enhance product quality and increase profitability for aquaculture enterprises. We have continued a selective breeding program using males and females obtained from an F3 generation (Egypt strain). Female selection was based on highest total length, and male selection was performed using individuals with the best condition factor. Each selected broodstock group was placed in 200 m² concrete ponds using a sex ratio of 3 females to 1 male for every 3 m². From the fry obtained, three selections were performed. The first was conducted at 60 days of age, the second at 135 days (at this point the fish were separated by sex) and the last at 11.5 months. Our results indicated that the improved Egypt line performed better than the control and the wild lines. Fry produced from the Egypt line (F5) had higher growth than the fry obtained from the control and the wild line (after three selections). Significant differences were observed for both meat production (measured as fillet yield) and condition factor. In both cases, the Egypt line had higher values (31.2% and 1.98, respectively). Reproductive performance measured as fry production was significantly higher in the Egypt line. The improved Egypt line produced 54% more fry than the control line and 65% more than the wild line. In general, the improved Egypt line had better reproductive performance, survival and growth. This study was conducted as a collaborative effort between UJAT, OSU, the Aquaculture/ Collaborative Research Support Program (A/CRSP) and the office for Agriculture and Fisheries Development (SEDAFOP) in Tabasco. This combined effort has allowed us to work at the "Jose Narciso Roviroso" hatchery (using 200, 1000 and 2000 m² ponds) and to use fish first selected by Mario Fernandez in 2003.

INTRODUCTION

Tilapias are commonly known in Mexico as “mojarras”. They belong to the family *Cichlidae* and are native to Africa. These fish are commonly used in aquaculture around the world due to their high quality of meat and ease of culture. Tilapias have been shown to be the species with the highest production potential, capable of contributing to the solution of global demand for fish.

Genetic improvement in aquaculture offers an opportunity to increase production, product quality and overall profitability. Current technologies can be implemented to improve quantitative characters that have economic value; however, the techniques for improvement that allow for genetic gains must include the formal definition of the breeding objectives, genetic estimation parameters that describe populations, and their differences (Davis and Hetzel, 2000).

In Latin America, broodstock and seed supply have been identified as one of the major constraints to production increases. In the 2001 expert panel meeting organized by the PD/A CRSP, inadequate availability and quality of fry (and broodstock) were listed as a research priority. In Mexico, there has been little effort given to the conservation and genetic selection of tilapia. This is despite the fact that these fish were introduced over 35 years ago, resulting in benefits related to food production (Garduño and Muñoz, 2001). In southeastern Mexico, tilapia broodstock and fry quality are particularly poor. In the region, tilapia culture has been the principal aquacultural activity since the early 1970s. Unfortunately, the loss of the introduced lineages, the lack of effective genetic selection programs, and poor management decisions have created disappointment and uncertainty regarding tilapia culture.

In the state of Tabasco, we initiated a genetic improvement program for Nile tilapia (*Oreochromis niloticus*) in the year 2000. The selection process, based on fish mass, allowed for the production of an improved line based on growth features. Three generations have now been obtained from the broodstock and the line is available for commercial use in aquaculture centers. This has allowed for the production of high quality fry which has increased production on the farms. In 2002 we initiated the evaluation of wild tilapia from four regions of the state. Our intention was to incorporate these lines into aquaculture and determine the feasibility of increasing gene diversity by selecting fish with the best characteristics in a breeding group.

METHODS AND MATERIALS

This study was conducted at the State tilapia hatchery “Jose Narciso Roviriosa” located in Teapa, Tabasco, as a collaborative effort between UJAT and the office for Agriculture and Fisheries Development (SEDAFOP) of Tabasco. Three lines of tilapia were evaluated: 1) the line that the “Mariano Matamoros” hatchery has traditionally used (control), 2) a wild line from the Usumacinta river basin (F3; WP10/CRSP project) and 3) the Egypt line (F4; WP11/CRSP project) improved under CRSP support.

Fry production

Two hundred females and 66 males were selected as broodstock for each line (control, wild and improved Egypt). Female selection was based on highest total length and male selection was performed using individuals with the best condition factor. Each selected broodstock group was placed in 200 m² concrete ponds using a sex ratio of 3 females to 1 male for every 3 m².

Growth Performance

Fry were collected from the spawning ponds and 28,000 fish from each group were stocked in 2,000 m² grow-out earthen ponds. Fish were fed five times a day with a daily ration of 5% of the estimated biomass. Feeding charts were constructed from samplings performed every two weeks. Final sampling was conducted after 60 days of grow-out and statistical comparisons were conducted performing a one-way ANOVA using STATGRAPHICS plus® 4.0 software.

Line Selection

Each selection was conducted following the mass selection criteria proposed by Sánchez and Ponce de León (1988). Ten percent (2,800) of the fish from the growth performance phase were randomly collected from each line to perform sampling. Based on the sampling results, fry were divided into three groups using weight as the selection variable: 1) fry which were 33% above the median value, 2) fry which were 33% around the median value, and 3) fry which were 33% below the median value. Group 1 was reserved for follow-up studies, and group 2 was used for line selection. All fish in group 3 were discarded. From group 2 (of each line), 14,000 fish were stocked in 2,000 m² earthen ponds (7 fish per m²) and grown-out for three months. At the end of the grow-out phase, 35% of the population (4,900 fish) that had the highest length were selected. From this group; fish were separated by sex for final grow-out. Two thousand females and 1,200 males were placed in earthen ponds. After six months of growth, the fish with the highest length (females) or condition factor (males) were selected to produce the F5 generation. Fry production from each line was evaluated during two reproductive cycles.

Comparative tests

Comparative tests were used to evaluate growth performance of new lines. These tests were conducted using adult fish. Fifty fish from each line were placed in 2-m³ floating cages located in a 1,000 m² concrete pond. Fish were fed to satiation three times a day using commercial diet pellets (Silver CupTM). This test was run in triplicate for 210 days. Final weight, final length, growth rate, feed conversion rate (FCR), condition factor (K) and fillet yield were measured as response variables. Water quality in the pond was maintained by exchanging 10% of the water volume daily.

Heritability

Heritability was estimated using the formula proposed by Sanchez and Aguilar (1988). This method estimates the relative contributions of differences in genetic and non-genetic factors to the total phenotypic variation in a population. The proposed formula is $h^2 = V_a / V_p$; where V_a is the additive genetic variation and V_p is the phenotypic variation.

Water quality

Dissolved oxygen (DO) and temperature were measured daily using a digital DO meter (YSI[®] 55) while pH was measured using a pH meter (Hanna instruments[®]). Phosphates, nitrates, nitrites and ammonia were measured weekly using a Hanna instruments[®] multiparameter kit.

RESULTS

Growth Performance

Analysis of variance of 10% of the fish stocked for growth performance showed significant differences between treatments after 60 days (Table 1). Fish from the Egypt and the control line showed similar final weights (6.04 and 6.28 g, respectively), while the fish from the wild group only reached 5.48 g. The interaction of weight and survival resulted in higher biomass produced in the control line (124.6 kg), followed by the Egypt line (121.1 kg) and the wild line (108.3 kg). Survival was higher in fish from the Egypt line (71.6%) followed by the control line (70.8%) and the wild line (70.6%).

Selection

According to the methodology, the fish obtained from each line from the growth performance phase were divided into three groups based on frequency distributions of their weight. Fourteen hundred fish were selected from group 2 and used for the second selection. After 90 days of growth, all fish were collected and sampled. Significant differences in final weights were found between treatments (table 2). Fish from the Egypt line were the largest (40.1 g) followed by the wild line (32.9 g) and the fish from the control group were the smallest size (30.2 g). Survival was higher in fish from the Egypt line (80.5%) followed by the control line (77%) and the wild line (61%). The best feed conversion rate (FCR) was seen in the Egypt line, while the control and the

wild line had similar rates. Figure 1 shows the growth of these fish. By day 15 there was a significant difference for the Egypt line. This difference remained until the end of the trial.

Broodstock selection

Fish with the highest length and best condition factor were selected to produce the F5 generation. A total of 200 females and 66 males were selected from each line. Higher weights and condition factors were obtained from the Egypt line for both sexes. Total length, weight, and condition factor for each line are shown in table 3.

Comparative tests (growth performance)

Table 4 shows the results from measurements of fish obtained from our F5 generation. The best growth was seen in the Egypt line (439.5 g and 28.1 cm), followed by the control line, while the lowest growth was seen in the wild group. However, due to differences in initial weight and length, the growth rate was slightly higher for the wild fish than that for the control group. Feed conversion rate was lower for the Egypt line. Significant differences were observed for both meat production (measured as fillet yield) and condition factor. In both cases, the Egypt line had larger values (31.2% and 1.98, respectively). Figure 2 shows the growth patterns (weight) for the three lines evaluated. After three months, the improved Egypt line separated from the wild and the control fish. This trend was stronger after five months of growth, reaching an estimated growth rate of 1.74 g/day. The lowest values were observed for the wild line.

Reproductive performance

The total number of fry produced during the two cycles was higher in the improved Egypt line than the Control and wild lines. In two months, 271,000 fish were produced by the Egypt broodstock while the Control and the wild line produced 176,200 and 145,800, respectively. The control fish produced fewer fry than the wild fish during the first cycle; however, during the second reproductive cycle this trend was reversed (table 5).

Genetic improvement

After five years of line selection, our improved Egypt line has shown a steady genetic gain (figure 3). The heritability values show a significant gain during the first selection (F1) in 2002. After that year, lower, but consistent gains have been obtained for the last three generations (F2, F3 and F4). During this last year the heritability value reached 0.24 for both sexes, indicating that the line selection continues providing significant genetic improvement.

Water quality

All water quality parameters measured during the current investigation were generally within the limits for tilapia aquaculture (table 6). Mean values for dissolved oxygen, temperature and pH were 5.07 ± 1.17 mg/L, 25.6 ± 2.9 °C and 6.53 ± 0.19 , respectively. Nitrites ranged between 0 and 0.25 mg/L, nitrites between 0 and 25 mg/L, phosphates between 0 and 0.8 mg/L and ammonia between 0 and 0.25 mg/L. In some situations, however, relatively high levels of nitrites were seen during low oxygen conditions.

DISCUSSION

Results from this study indicate that the improved Egypt line performs better than the control and wild lines. The Egypt line had better growth parameters than the other two lines. In general terms, fry produced from the Egypt line (F4) had higher growth than the fry obtained from the control and wild line (after three selections). Our improved line has shown better indicators of growth after each selection. Similar results were found by Doyle and Talbot (1986). After five generations; these authors showed that better growth was achieved after each generation. The growth rate obtained for juveniles in this study was 0.36 g/day; while Garduño (1999) obtained a growth rate of 0.17 and 0.16 g/day when comparing early growth of *O. niloticus* and a red hybrid.

During the juvenile phase, our improved line showed similar weight values to those achieved by Green (1999) who reported 37.1 g of growth for fish cultivated during 67 days in Honduras. Condition factor is an index based on a ratio between growth and length, which is a general indication of the robustness of fish (Rodríguez, 1992). Condition factor for juveniles and adult fish showed significant differences between the Egypt and control and wild lines, indicating that fish from the improved line were more robust than the other two lines. Our results show higher condition factors than those obtained by Green (1999) in earthen ponds.

Our improved adult fish also had the best growth rate than the other two lines used in this study (1.74 g/day). This line increased 31.8% more daily than the other two lines. Brezeski and Doyle (1995) reported a significant growth response from selected fry, being 2.3% higher than that obtained from the controls. Liti *et al.* (2005) found that fish from three strains (Lake Victoria, Lake Turkana, and Sagana fish farm) had growth rates of 1.0 and below; however, those fish were grown using inorganic fertilizer supplemented with wheat bran. Interestingly, all strains used in the experiment had higher condition factors than the lines used in our study (meaning that the African fish are more robust). The growth rates recorded in our study were higher than those reported by Khater & Smitherman (1988); these authors evaluated three strains of *O. niloticus*, obtaining growth rates between 1.45 and 1.63 g/day.

Reproductive performance measured as fry production was significantly higher in the Egypt line. The improved Egypt line produced 54% more fry than the control line and 65% more than the wild line. These results are very similar to those obtained in our previous selection trials (Fernández-Perez, 2004).

All water quality parameters measured during the current investigation were generally within the limits for tilapia aquaculture (Aguilera, 1985; Steffens, 1987; Morales, 1991).

After five years of line selection, our improved Egypt line has shown a steady genetic gain. It is important to highlight that positive values indicate that there is no need for introducing new individuals into the genetic pool yet. Our heritability values for the improved Egypt line indicate that the line selection continues to provide a significant genetic gain. Similar results have been reported by Sánchez and Aguilar (1988), Sánchez *et al.* (1995), Zosipat and Circa (1997) and Basiao and Doyle (1999) who reported significant gains after several years of genetic improvement in tilapia.

ANTICIPATED BENEFITS

From the beginning of this project in 2001 our main goal was to produce high quality tilapia seed. We have obtained five generations of the improved Egypt line (locally known as the Tabasco line). These fish have been used as broodstock and the fry produced from these generations have been distributed to the following farms:

Piscifactoría de Teapa (State hatchery): 100% of the broodstock lot has been replaced. Every year fish were renewed with our line as follows:

3000 ♀ and 1000 ♂ 2nd generation (F2) in 2003

1600 ♀ and 534 ♂ 3rd generation (F3) in 2004

1600 ♀ and 534 ♂ 4th generation (F4) in 2005

1600 ♀ and 534 ♂ 5th generation (F5) in 2006

Granja Kab'ja: Received 1000 ♀ and 500 ♂ 3rd generation (2004)

Centro Acuícola Ayuntamiento del Centro: Received 600 ♀ and 200 ♂ 3rd generation (2004).

Aquaculture Laboratory at the Biological Sciences Division, UJAT. Received:

200 ♀ and 100 ♂ 2nd generation (F2) in 2003

200 ♀ and 100 ♂ 3rd generation (F3) in 2004

200 ♀ and 100 ♂ 4th generation (F4) in 2005

Granja TILASUR, Reforma, Chiapas: Received 800 ♀ and 400 ♂ 4th generation (F4) in 2005.

Peten, Guatemala: Received 200 ♀ and 100 ♂ 4th generation (F4) in 2005.

Grupo La Esperanza, Pino Suárez Jonuta. Received:

200 ♀ and 100 ♂ 3rd generation (F3) in 2004

200 ♀ and 100 ♂ 4th generation (F4) in 2005

Farm “La Palma”, Tenosique: Received 200 ♀ and 400 ♂ 4th generation (F4) in 2005.

Farm “Oxiacaque”, Nacajuca. Received

200 ♀ and 100 ♂ 3rd generation (F3) in year 2004

200 ♀ and 100 ♂ 4th generation (F4) in year 2005

Tilapia Anaya, Palizada, Campeche: Received 800 ♀ and 400 ♂ 3rd generation (F3) in 2004.

State of Querétaro government: Received 1000 ♀ and 300 ♂ 2nd generation (F2) in 2003.

State of Hidalgo government: **Received 1000 ♀ and 300 ♂ 2nd generation (F2) in 2003.**

We can conclude that our main goal has been achieved since we have produced and distributed 13,200 ♀ and 4,800 ♂ genetically improved adult fish during this project.

Fry production

Production of fry is the principal objective of the state hatchery “Mariano Matamoros”. Most fish produced are provided to small tilapia farmers and the rest are used for restocking freshwater lagoons where tilapia are the main fishery for the surrounding towns and villages. Fry production has been significantly increased following genetic improvement. In 2001 only 1 million fry were produced in the hatchery; in 2006 fry production reached 8 million, with 100% of the reproduction ponds being occupied with the improved Tabasco line.

Training

To date, ten workshops on tilapia broodstock handling and selection have been implemented. Each farm that received the improved line, as well as students and professors from the University of Tabasco, has received this training. In 2005 we also implemented a 10-week workshop in aquaculture where broodstock handling and selection was one (of 10) topics taught.

Outreach

Publication and distribution of the manual “tilapia broodstock handling and selection”

Publication and distribution of Aquaculture CRSP final reports.

Presentations at national scientific meetings:

VII Simposio Internacional de Tilapia, Veracruz, México (2006)

X Convención Nacional de Veterinaria, Villahermosa, Tabasco (2006)

XIII Congreso Latinoamericano de Acuicultura. Villahermosa, Tabasco (2005)

VIII Congreso Nacional de Ictiología. Villahermosa, Tabasco (2005)

II Simposio Internacional de Acuicultura, Guadalajara, México (2004)

Simposio Internacional de Acuicultura “ACUACUBA 2003”, la Habana, Cuba (2003)

Simposio Internacional de Acuicultura “AQUAMAR 2002”, Cancún, México (2002)

Adult fish have been exhibited at the state fair every year from 2003 to 2007.

Mario Fernández was interviewed on television during the program “ecos del campo”
 Mario Fernández was interviewed on the radio during the program “UNIVERSITAS”

All of these actions have aided in the distribution of high quality tilapia fingerlings in south eastern Mexico.

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Table 1. Growth performance (mean \pm SD) of fry produced by broodstock selected for each line after 60 days of experimentation. The number of fish stocked per line was 2,800 with an initial average weight of 0.02 g. Different letters indicate significant differences ($p < 0.05$).

	Egypt	Control	Wild
Fish harvested	20,048	19,824	19,768
Final weight (g)	6.04 \pm 2.12 ^a	6.28 \pm 2.62 ^a	5.48 \pm 2.45 ^p
Final Biomass (kg)	121.1	124.6	108.3
Survival (%)	71.6	70.8	70.6
Growth rate (g/day)	0.10	0.10	0.91
FCR	2.26	2.34	2.37

FCR, feed conversion rate.

Table 2. Growth performance (mean \pm SD) of juveniles produced by broodstock selected for each line after 90 days of experimentation. The number of fish stocked per line was 14,000. Different letters indicate significant differences ($p < 0.05$).

	Egypt	Control	Wild
Initial weight (g)	7.01 \pm 1.06	7.79 \pm 3.0	6.87 \pm 3.06
Initial length (cm)	7.49 \pm 0.9	6.92 \pm 0.94	6.47 \pm 1.27
Final weight (g)	40.15 \pm 2.59 ^a	30.17 \pm 9.55 ^c	32.96 \pm 8.70 ^b
Final length (cm)	12.31 \pm 0.28 ^a	11.56 \pm 1.10 ^c	12.03 \pm 0.93 ^b
Growth rate(g/day)	0.36	0.24	0.28
Survival (%)	80.5	77.0	61.0
FCR	1.7	2.7	2.6
K	2.15 \pm 0.13 ^a	1.95 \pm 0.38 ^b	1.89 \pm 0.21 ^c

Abbreviations: FCR, feed conversion rate; K, condition factor.

Table 3. Mean values (\pm SD) of fish selected as broodstock for the three lines.

Line	Sex	Selected fish	Length (cm)	Weight (g)	K
Egypt	Females	200	22	241 \pm 19.37	2.26
	Males	66	23	293 \pm 12.29	2.40
Control	Females	200	22	209 \pm 47.30	1.96
	Males	66	23	246 \pm 41.23	2.02
Wild	Females	200	22	203 \pm 49.30	1.90
	Males	66	24	228 \pm 45.23	1.64

K, condition factor.

Table 4. Growth parameters (mean ± SD) for the three lines. Different letters indicate significant differences (p < 0.05).

	Egypt	Control	Wild
Initial weight (g)	72.3	89.7	72.6
Initial length (cm)	15.87	16.77	15.98
Final weight (g)	439.47 ± 17.39 ^b	368.78 ± 20.32 ^d	353.65 ± 20.00 ^e
Final length (cm)	28.07 ± 0.73 ^a	26.93 ± 0.76 ^b	26.52 ± 0.69 ^c
Growth rate (g/day)	1.74	1.32	1.33
FCR	1.7	2.2	2.3
K	1.98 ± 0.13 ^a	1.88 ± 0.14 ^b	1.89 ± 0.13 ^b
Fillet yield (%)	31.24	29.20	28.92

Abbreviations: FCR, feed conversion rate; K, condition factor.

Table 5. Fry production during two reproductive cycles for the three lines.

Line	1st cycle		2nd cycle		Total	
	Fry produced	Fry/female	Fry produced	Fry/female	Fry produced	Fry/female
Egypt	117,200	586	153,800	769	271,000	1,355
Control	47,000	235	129,200	646	176,200	881
Wild	74,200	371	71,600	358	145,800	729

Table 6. Water Quality in all ponds where the three lines were evaluated.

	AVERAGE	SD	MIN	MAX
Egypt				
Dissolved Oxygen (mg/L)	5.06	1.10	2.8	6.6
Temperature (°C)	25.57	3.01	22.0	29.7
pH	6.41	0.18	5.7	7
Nitrites (mg/L)	0.194	0.027	0.0	0.25
Nitrates (mg/L)	15.362	0.950	0.0	25.0
Amonia (mg/L)	0.154	0.009	0.0	0.2
Phosphates ((mg/L)	0.048	0.014	0.0	0.8
Control				
Dissolved Oxygen (mg/l)	4.95	1.20	2.5	6.3
Temperature (°C)	25.46	2.90	22.5	29.4
pH	6.59	0.20	5.8	7.1
Nitrites (mg/L)	0.146	0.023	0.0	0.25
Nitrates (mg/L)	13.587	0.870	0.0	25
Amonia (mg/L)	0.138	0.006	0.0	0.25
Phosphates ((mg/L)	0.073	0.017	0.0	0.6
Wild				
Dissolved Oxygen (mg/l)	5.19	1.20	3.8	6.5
Temperature (°C)	25.81	2.80	22.9	29.4
pH	6.59	0.18	6.3	7.0
Nitrites (mg/L)	0.149	0.028	0.0	0.25
Nitrates (mg/L)	13.887	0.720	0.0	25
Amonia (mg/L)	0.138	0.005	0.0	0.25
Phosphates ((mg/L)	0.073	0.017	0.0	0.6

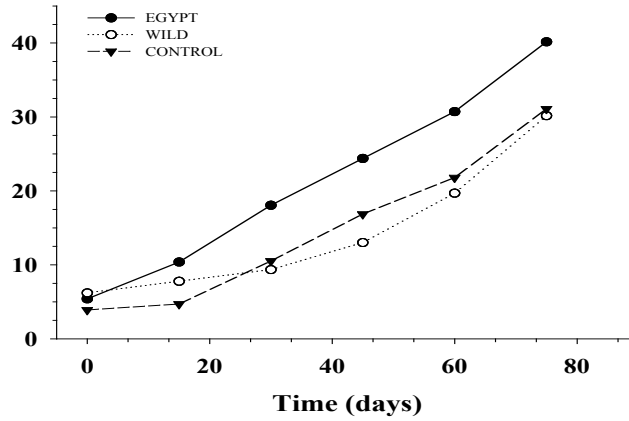


Figure 1. Average weight of fish produced in the three lines. Fish were sampled every 15 days.

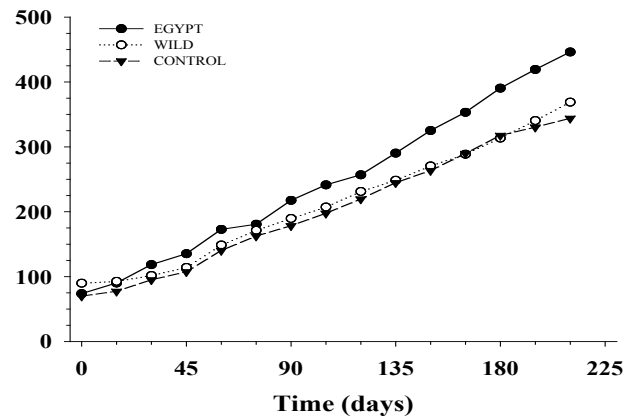


Figure 2. Average weight for the three lines evaluated during the comparative tests (210 days).

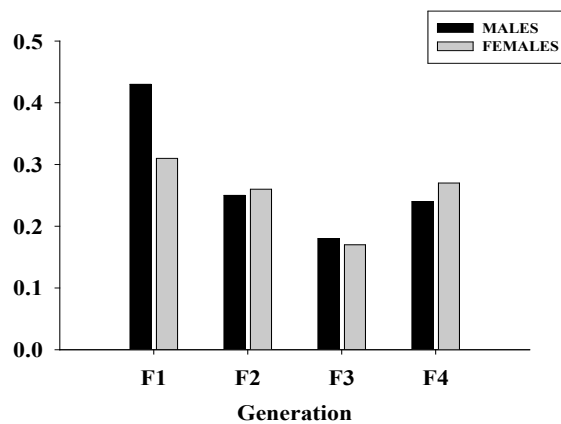


Figure 3. Heritability values for the improved Egypt line for the four generations produced.

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

*Twelfth Work Plan, Seedstock Development & Availability 4 (12SDA4)
Final Report
Published as Submitted by Contributing Authors*

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ABSTRACT

The results of this study successfully established that wild common snook begin their gonadal sex differentiation within the first few months of life as males, and that they remain in an immature state for at least during their first two years of life. Experiments were conducted in the laboratory to determine the effects of temperature and estradiol-17 β on the pattern and timing of gonadal sex differentiation using wild-caught juvenile snook. The treatments were successfully applied. However, the results of the temperature manipulation yielded inconclusive results due to the unexpected lack of development of the gonads; and the estrogen exposure experiment suffered a catastrophic incidence of mortality. Overall, these observations in the laboratory indicate that wild young snook may have difficulty adapting to laboratory environments and that husbandry techniques need to be further refined for this species. In this regard, in a pilot trial we were able to wean juvenile snook to accepting prepared diets. This development will greatly facilitate continued research and development of common snook husbandry techniques.

INTRODUCTION

Artisanal fisheries based on the capture of wild populations are the primary current source of fish for the food market in the southern region of Mexico. However, because of its geographic and hydrological features, this region also has been considered one of the most promising areas in Mexico for the development of aquaculture. Although native fishes are deeply embedded in the culture of the region and constitute important food staples for its people, to date most aquacultural programs have relied primarily on nonnative species such as tilapias and carps. These exotic species have escaped the confines of aquacultural farms and are now reported to have invaded biologically sensitive areas such as The Pantanos de Centla Biosphere Reserve (Tabasco), the most important wetland system in southeastern Mexico. The impact of these exotics

on the ecological viability of the area remains largely unexplored but is likely to be considerable. This proposed work is based on the premise that the development of aquaculture of indigenous species is preferable for the region in the context of both market acceptability and ecological compatibility.

Species of “robalo,” or snook, are among the most important indigenous fish species along the Mexican coastline of the Gulf of Mexico. Among the species of snook, the “robalo blanco”, or common snook (*Centropomus undecimalis*) are caught in relatively greater numbers and enjoy a high market value (Anonymous, 2002). During the last few years, the average annual catch for common snook has been approximately 5,000 tons in Mexico, and 900 tons for the state of Tabasco (Anonymous, 2002). However, there is an overall national trend for diminishing catch volumes despite occasional and short-lived local increases, a situation that has led to concerns for the health of the regional snook fisheries and to calls for improved management practices (Anonymous, 2002). The natural range of common snook extends from North Carolina to Brazil (Muller et al., 2001), and therefore the status of natural snook populations is also of international concern. In places such as Florida (USA), common snook were until recently considered a “species of special concern” for which commercial harvest was banned, and strict management regulations are currently in place for its recreational fisheries (Anonymous, 2001).

Knowledge of the reproductive biology of common snook is limited. Histological observations of the gonads of fish collected from the field are consistent with the concept that common snook are protandric hermaphrodites. Namely, they appear to first develop as males and thereafter reverse into females. In Florida, all fish younger than 1-2 years (depending on site of collection) seem to be males, an even sex ratio is observed at 5-7 years, and most fish older than 12-15 years seem to be females (Taylor et al., 2000). Interestingly, the available data (Taylor et al., 2000) also indicates that within the same age class, females are larger than males. This size differential is particularly pronounced in younger fish, 1-2 years old, where the fork length of females is 60-70 percent longer than that of males (Tables 2 and 3 in Taylor et al., 2000). The spawning season for common snook runs from spring through early fall, depending on the geographical location, during which they spawn multiple times (Peters et al. 1998; Taylor et al. 1998). Although it is sometimes assumed that sex reversal in common snook occurs after their first spawning (Muller et al., 2001), there is histological evidence suggesting that males may retain their gender through consecutive spawning seasons (Grier and Taylor, 1998). Additional studies are clearly needed to obtain a better knowledge of the reproductive biology of common snook. Further, most studies of common snook reproduction have focused on Florida populations and research with populations in other geographical locations is necessary to determine the general applicability of the results obtained.

Techniques for aquaculture production of snook are at present not fully developed. Snook broodstock has been difficult to maintain in captivity and thus the few available hatchery-spawning programs have relied on wild-caught fish. Wild-caught broodstock are either immediately processed upon capture to obtain gametes for in vitro fertilization, or they are brought to the hatchery where they are promptly injected with hormones to induce spawning (Anonymous, 2001). Fingerlings for stocking purposes have been successfully produced using this technique.

The finding that female snook are larger than males of the same age class, especially in the younger fish (see preceding discussion), suggests that females have an intrinsically faster growth rate than males. This finding has obvious and important relevance for the development of aquacultural techniques for snook. For example, sex determination in most fishes is readily manipulated by exogenous administration of sex steroids early during gonadal development (Schreck, 1972; Hunter and Donaldson 1983; Contreras, 2001). Also, in many species including those with strong genetic determinants of sex, sex ratios can be manipulated by changes in water temperature (Strüssmann and Patiño, 1995, 1999; Patiño et al., 1996). Control of sex ratios by environmental techniques such as water temperature has the advantage that they are not associated with real or perceived concerns for the use of steroids (“endocrine disruptors”) in

aquaculture. Therefore, this proposed project is designed to determine if sex ratios of common snook can be changed in favor of females by manipulation of water temperature or application of exogenous sex steroids (estrogen), and if growth rate is associated with gender. To our knowledge, the effects of temperature on sex determination of naturally hermaphroditic teleost species have not been examined, but in other protandric teleosts the exogenous administration of estrogens generally results in female formation (Guigen et al., 1993; Condeca and Canario, 1999; Lee et al., 2000).

The development of an aquaculture industry for common snook would benefit the Gulf Coast region of Mexico for various important reasons. It would be consistent with regional plans for the development of aquaculture as a source of income and of food fish. It would also be consistent with the common-sense premise that the use of indigenous species for aquaculture has a much lower probability of causing ecological damage compared to exotics such as tilapias or carp (see preceding discussion). Finally, it would provide relief from the intense fishing pressure currently being exerted on wild snook populations.

METHODS AND MATERIALS

Experiment 1: Timing and morphological pattern of gonadal sex differentiation in common snook

Experiment 1a: Rio Grande/Rio Bravo, USA and Mexico

The study area began at the mouth of the Rio Grande/Rio Bravo, which connects to the Gulf of Mexico, and extended 51.5-km upstream (Figure 1). Sampling effort was confined to the U. S. side of the river. The banks near the river mouth were not well defined and in some areas resembled tidal flats and pools with a sandy substrate. There was little submerged vegetation, and shoreline vegetation consisted primarily of Poaceae grass and two small patches of black mangrove, *Avicennia germinans*. The habitat gradually changed up-river to a substrate of silt and mud with more canalized banks and shrubby vegetation (mesquite, *Prosopis glandulosa*, and Texas ebony *Pithecolobium flexicaule*) along the shoreline. Agriculture is the predominant land use practice beyond the river banks. Fish were collected from January 1, 2006 through March 25, 2006. These months were selected for sampling because a pilot study conducted in 2005 suggested that both age-1 and age-2 juvenile common snook are present in the river simultaneously during this time of the year (C. G. Huber et al., unpublished data). Three different gears (trawl, castnet and electrofisher) were used to capture fish in the various river habitats. A total of 211 common snook was collected.

Fish age was initially determined using a length-frequency histogram (DeVries and Frie, 1996). We were able to easily distinguish age-1 and age-2 juvenile common snook (all fish were assigned a 1 January birthdate). We then processed a subsample of otoliths in order to verify our initial age estimations. Whole otoliths were read using reflected light and a dissecting scope (10X magnification) as described by Taylor et al. (2000) for common snook. Otoliths were used to develop an age-length key to classify juvenile common snook into age groups. Otoliths were aged by two readers independently. If the readers disagreed on the age of an otolith, they were re-read by both readers again. If a consensus could not be reached, a third reader was used; in these instances, fish age was assigned based on agreement of two readers.

Gonads were processed according to standard histological procedures (Luna, 1992). Tissues collected in the field were post-fixed in Bouin's fixative for 48 h, rinsed in tap water overnight, dehydrated in a series of ethanol baths, cleared in xylene, and infiltrated with paraffin. Paraffin blocks were sectioned (6-8 μ m) using a microtome. Central cross-sections of each gonad were placed on pre-cleaned slides and stained using Weigert's hematoxylin and eosin. Gonad sections were viewed with a compound microscope and classified into ad hoc stages according to size and tissue organization. Criteria used for gonadal differentiation were as described by Patiño and Takashima (1995).

Experiment 1b: Tabasco, Mexico

Fry collection and acclimatization. Despite several attempts for two consecutive years for producing fingerlings in captivity, successful fertilization of the eggs was not achieved. We were able of obtaining ripe females, but artificial fertilization failed. Therefore, young of the year were caught in the wild. Coastal lagoons of Tabasco were sampled at the starting of the spawning season of the common snook in the year 2003. Small snooks were located nearby mangrove areas of the Arroyo Verde (a tributary of the Carmen-Pajonal-Machona coastal lagoon system) Paraíso, Tabasco (Figure 2). Eighteen samplings were performed from October, 2003 to February, 2005. A total of 286 wild fish were collected using a 15-m long mosquito mesh net. Fish were transported to the aquaculture laboratory at UJAT using a 500-L tank with diluted marine water (10 ppm). Once in the laboratory, all fish were killed with an overdose of anesthetic (MS-222). In the laboratory, total length (TL), was measured to the nearest mm; weights were measured to the nearest gram (g). Gonad samples were fixed in 10% buffered formalin or Bouin's solution for histological processing (depending on fish size). Sagittal otoliths were removed and stored dry for age determination from 229 organisms.

Otoliths were cut in sections of approximately 0.5 mm thick and were mounted on a microscope slide. Daily growth marks were counted on the section through the core by using a compound microscope and transmitted light. Two independent readers counted daily growth rings on each otolith without knowledge of fish size. If the two readings disagreed, both readers read the otolith again, for a total of four readings. If three of the four readings agreed, then this reading was accepted as a valid count.

Histological inspection of the developing gonads was conducted by microscopic examination (10, 40 and 100X) using preparations in hematoxylin and eosin (Allen, 1992; Aguilar et al., 1996). Criteria used for gonadal differentiation were as described by Patiño and Takashima (1995).

To determine if there is a close relation between age and size (total length or weight) during the first months of development, an analysis of regression was conducted using the statistical package Statgraphics® v. 4.0. A logarithmic transformation was conducted to achieve normality and homoscedasticity of the variables length and weight.

Experiment 2: Effect of early treatment with low or high water temperature or sex steroid on the sex ratio and growth rate of common snook**Experiment 2a: Manipulation of water temperature**

Using results from experiment 1, all fish smaller than 80 mm in total length were considered as immature males (Morales, personal communication). Four-hundred-and-eighty wild fish were collected using a small bag seine (L = 15m, H = 2m, 1.5mm square mesh), nearby mangrove areas of the Arroyo Verde, Paraíso, Tabasco. Fish were transported to the aquaculture laboratory at UJAT using a 500-L tank with diluted marine water (10 ppm). Once in the laboratory, all fish were placed in 100-L plastic tanks. Due to manipulation, several fish presented skin lesions accompanied with fungal and bacterial infections; therefore, all fish were quarantined for two weeks at 20 ppm. Salinity in the water was gradually raised to reach 20 ppm by increasing 2 ppm/day.

The experimental temperatures in this study were established within the reported tolerance limits for snooks and included the following treatments: 17.5, 22.5, 27.5, 32.5 and 37.5 °C. The time of onset and the duration of the treatments were established based on the results of Experiment 1. The duration of the treatment covered the normal period of testicular differentiation, which was expected to last about four weeks (based on Strüssmann and Patiño 1995, 1999).

Five independent closed-recirculation systems were adapted with each of the experimental temperatures (Figure 3). All systems were located in an isolated room equipped with a 24,000 Btu/h air conditioner (Mini Split Aux[®] model ASW-24B2/EA) that maintained the room temperature around 16 °C. Each recirculating system consisted of three 70-L cylindroconical fiberglass tanks adapted to a 100-L reservoir containing a biological filter. Each system was equipped with a 1/6 hp submersible pump (Valsi[®], model AQUA99W) creating a flow of 10 L/min. Each experimental temperature was maintained using individual temperature control units (Yuyao[®], Model XMGT818) with titanium sensors adapted to 1000 and 2000 W heaters (depending the temperature needed).

Each treatment consisted of three replicates, due to fish availability, only ten fish were placed in each experimental unit. To ensure that fish have not undergone sexual differentiation, we used only fish between 40.65 and 57.43 mm (1.20 to 2.9 g). Fish were kept in the experimental treatments for 45 days. All fish were fed during the first 14 days with a mix of *Artemia nauplii* and adult *Artemia* biomass. At day 15 a conditioning regime to artificial food was initiated. Every three days, the proportion of *Artemia* biomass and commercial pellets (trout Silver Cup[™]; 45 % protein) was changed (3:1; 2:1 and 1:1). From day 24 and onwards, all fish were fed 100% commercial pellets. All fish were fed to apparent satiation five times a day, every 3 hours (between 7AM and 7 PM).

At the end of the experimental time, all fish were acclimated to room temperature (30 °C) allowing a steady change of 1 °C per day. At this time, weight and total length of all fish were recorded. Fish were kept for grow-out at 30 °C for 45 more days. All fish were killed with an overdose of anesthetic (MS-222) to determine if treatments resulted in feminization. Samples for histological inspection of the developing gonads were collected and fixed in Bouin's solution. Sex ratios were determined by microscopic examination (10, 40 and 100X) of gonads using preparations in hematoxylin and eosin (Allen, 1992; Aguilar et al., 1996). Criteria used for gonadal differentiation were as described by Patiño and Takashima (1995).

Dissolved oxygen, temperature and pH were monitored daily. These parameters were measured using a DO meter (YSI[®] 55) and a pH meter (Hanna Instruments[®]). Nitrates, nitrites and ammonia were measured weekly using a Hanna instruments[®] multiparameter kit. Diluted marine water was used and salinity was maintained at 10 ppm. To maintain water quality, 25 % of the water in the system was exchanged once a week.

Effects of treatments on final length and weight were determined by one-way ANOVA. Effects on survival were determined using a contingency table and differences determined by chi-square test. All statistical tests were conducted using the statistical package Statgraphics Plus[®] v. 4.0. Graphical analysis was conducted using the program Sigma Plot[®] v. 8.0.

Experiment 2b: Administration of estradiol-17 β .

Six-hundred-and-fifty wild fish were collected and transported to the aquaculture laboratory using the methods described above. This experiment consisted of six different E2-oral administration periods (7, 14, 21, 28, 35 and 42 days) and a control group fed commercial pellets with no E2. Once again, we estimated that the duration of the treatment covered the normal period of testicular differentiation. All treatments were placed in a closed-recirculation system consisting of 21 cylindroconical fiberglass tanks (70-L capacity) adapted to a 500-L reservoir containing a biological filter (Figure 4). The system was equipped with a 3/4 hp suction pump that pass the water through a sand filter (STA-RITE[®], model JWPA-230A) creating a flow of 2.5 L/min in each tank.

Each treatment consisted of three replicates, due to fish availability, only twenty fish were placed in each experimental unit. To ensure that fish have not undergone sexual differentiation, we used only fish between 40.65 and 57.43 mm (1.20 to 2.9 g). Once each feeding regime ended, fish were kept in the experimental units until the end of the longest treatment (42 days). All fish were fed

during the first 14 days with a mix of E2-enriched *Artemia nauplii* and adult *Artemia* biomass. At day 15, a conditioning regime to E2-enriched artificial food (trout Silver Cup™; 45% protein) was initiated. Every three days, the proportion of *Artemia* biomass and commercial pellets was changed (3:1; 2:1 and 1:1). From day 24 and onwards, all fish were fed 100 % E2-enriched commercial pellets. *Artemia* and biomass enrichment was conducted following the methods reported by Stewart et al. (2001), Contreras et al. (2003) and Vidal-López (2004) using a dose of 50 mg/L. Commercial pellets were enriched with a dose of 50 mg/Kg (Green et al., 1997). Control food was sprayed with ethanol (used as vehicle for enrichment). All fish were fed to apparent satiation five times a day, every 3 hours (between 7AM and 7 PM).

At the end of each experimental time, all fish were fed with commercial pellets without E2. When all treatments ended (42 days), the weight and total length of all fish were recorded. Due to severe mortality rates during sampling, all fish sampled at this time for histological inspection to determine if treatments resulted in feminization. Sex identification, water quality and statistical methods were the same described in experiment 2a.

RESULTS

Growth and gonadal Sex differentiation

In the Rio Grande/Rio Bravo, at least two size groups were evident from the length-frequency histogram: 46 to 156 and 198 to 303-mm SL; and a single fish was caught that appeared to be of a larger size class (360 mm SL) (Figure 5). We performed otolith and gonadal analysis on 41 individuals. These analyses confirmed that otoliths from the smaller size class (46 to 156-mm SL) contained a single annulus still in the process of formation (age 1) and also had relatively small gonads (Figure 6). A cavity could be recognized near the hilar region of the gonads of these fish that resembled a sperm duct (Figure 6). Age-1 common snook were therefore classified as juvenile males. Otoliths taken from the second size class (198 to 303 mm SL) showed two annuli (age 2) and their gonads were larger but still classified as juvenile males (Figure 6). Otoliths and gonads from the 360-mm fish were not analyzed, but separate analyses of common snook of similar size suggested that this fish was age-3 or older and may have been a mature adult.

In Tabasco, we examined otoliths from 189 of the 229 samples collected. Age determination was validated for fish between 67 and 130 days old. However, ages above 100 days should be regarded with caution due to ring overlapping. Thirty individuals ranging in size from 30.5 to 61.8 mm (TL) had undeveloped gonads (they could not be located). The estimated age for these fish varied from 67 to 77 days. Forty-two fish, ranging in size from 62.6 and 99.8 mm and estimated age from 77 to 89 days, were classified as undifferentiated. The undifferentiated gonads appeared as two thin stripes at both sides of the body between the kidneys and the gas bladder (Figure 7). They contained a thick epithelial tissue continuous with the peritoneal epithelium. Some primordial germ cells (PGC) were found dispersed between the epithelial cells. The PGC are large cells with round nucleus and clear cytoplasm. Eight fish were classified as males with testis under early formation (early testicular formation) (Figure 8). These organisms had a total length range between 110.1 and 210.5 mm and their estimated age varied from 92 to 123 days. The primordial germ cells had started to organize in clusters, these PGC are differentiating into spermatogonia which become visible as large cells with clear cytoplasm, large, round and central nucleus, and a distinct nucleolus. Some of these cells show mitotic activity. Fifty additional fish had advanced testicular formation (Figure 9). The total length range of these fish was 60.8 to 230.5 mm. The age of these fish was estimated between 108 and 130 days. The structure of the testis at this stage is clear, the spermatogonia are organized in groups at the periphery of the testis, and some Sertoli cells are observed. The germinal epithelium grows from these peripheral groups to the middle region of the testis, forming lobular structure without lumen. In the middle and dorsal region of the testis the principal duct is formed (Figure 10). All fish differentiated or in the process of gonadal differentiation showed a developmental pattern towards testis. No significant relation ($P > 0.27$) was detected between age and growth (total length or weight). The amount of variability in the data explained by the model was lower than 3% (Figure 9).

Effects of temperature on gonadal sex differentiation

All fish kept at 37.5 °C died at day 12 of experimentation indicating that this temperature is higher than the lethal limit for the species. All other treatments were finished as expected. Despite that all fish were larger than the size at which gonadal differentiation occurs, all fish sampled were histologically immature. Therefore, we were not able to determine if temperature has an effect on the pattern or timing of gonadal sex differentiation.

At the end of treatments, statistical significant differences were observed for length and weight ($P < 0.01$) (Figure 11). Fish kept at 32.5 °C had the highest (114.86 ± 1.19 mm) and those at 17.5 °C had the lowest size (81.7 ± 2.14 mm). Similar results were found for weight (figure 8). Significant differences were also observed in survival rates ($P < 0.01$). Survival was good in all treatments (except at 37.5 °C). Lowest survival was observed in fish kept at 27.5 and 22.5 °C (50 and 60%, respectively), while fish kept at 17.5 and 32.5 had the highest survival (97% for both treatments).

All water quality parameters were generally maintained within the limits for fish aquaculture. Mean values for dissolved oxygen and pH were 8.57 ± 0.04 mg/L and 7.76 ± 0.03 , respectively. Nitrates averaged 0.54 ± 0.07 mg/L, nitrites 0.24 ± 0.06 mg/L, and ammonia averaged 2.59 ± 0.24 mg/L (Table 1).

Effects of estradiol-17 β on gonadal sex differentiation

A high mortality event occurred at day 42 of experimentation; therefore, we decided to sample all treatments at this time in order to be able to analyze histological samples. Although most fish had already surpassed the expected size at which gonadal differentiation begins, only one fish had undergone testicular development in the control group, all other fish sampled histologically were immature. Therefore, we were unable to determine if administration of E2 had an effect on gonadal sex differentiation. Five fish from each experimental unit are currently on grow-out tanks, they will be sampled after 100 days of growth.

Statistical significant differences among treatments were observed for length and weight ($P < 0.05$) (Figure 12). Fish fed E2 for 21 days had the highest length (85.69 ± 1.45 mm), whereas fish fed E2 for 42 days had the lowest length (77.93 ± 0.94 mm). Fish in the control group had the largest weight, while fish fed E2 for 35 days had the lowest weight (fig. 9). At day 42 (time of sampling) no significant differences in survival were observed. All treatments ranged between 92 and 98%.

All water quality parameters measured during this experiment were in general within the limits for fish aquaculture. Mean values for temperature, dissolved oxygen and pH were 30.2 ± 0.14 °C, 6.52 ± 0.07 mg/L and 7.07 ± 0.23 , respectively. Nitrates averaged 0.54 ± 0.03 mg/L, nitrites 0.08 ± 0.01 mg/L, and ammonia averaged 0.09 ± 0.01 mg/L (Table 2).

DISCUSSION

In the Rio Grande/Rio Bravo, our sampling design allowed the capture of mostly of age-1 (2005 year class) and age-2 (2004 year class) juvenile common snook as determined by length-frequency histogram and otolith analysis. Histological examination of the gonads indicated that age-1 fish (<160 mm SL) were immature males with very small, pre-spermatogenic testes recognizable mainly by the presence of what appeared to be an early sperm duct. Age-2 fish (>160 to 303-mm SL) also had immature testes but at more advanced stages. Differences in size within each age group were presumably due to the protracted spawning period that is typical for common snook (April through September; Taylor et al. 1998). Given the small size and early developmental stage of age-1 testes, it is highly unlikely that any age-2 males reached breeding condition during their first potential spawning season as age-1 fish (spring-summer 2005). However, it is possible that age-2 fish reached maturity and bred for the first time during the 2006 breeding season. A previous study with common snook in Florida showed that spermatogenesis does not begin until late winter or spring (Grier and Taylor 1998), sometime following the sampling period for the present study. Because all age-1 and age-2 common snook captured in the present study were

males, the results of the present study are consistent with the previous conclusion that common snook are protandric hermaphrodites (Taylor et al. 2000).

In Tabasco, our results indicate that common snook from southern Mexico initiate gonadal differentiation between two and three months of age. All fish sexually differentiated or in the process of gonadal differentiation seemed to follow a male developmental pattern. These results coincide with observations made by Taylor et al. (2000) and by us in Texas, suggesting that common snook is a protandric hermaphrodite.

Gonadal sex differentiation seemed to begin within a wide range of size in snook from Tabasco; between 21 and 60 cm (or 92 to 123 estimated days). Very little information on juvenile snook growth is available and most research has been conducted in southern United States; particularly in the Florida peninsula where seasonal climate changes may have a strong effect on fish growth. However, in a study conducted on snook populations of the Puerto Rico Island (Aliaumea et al., 2000), the growth rate for common snook was estimated to be 0.44 mm/day. Other studies conducted in Florida reported growth rates varying from 0.6 to 1.0 mm/d (Fore & Schmidt 1973; Gilmore et al. 1983; and McMichael et al., 1989). It is possible that the growth rate for snooks in southeastern Mexico is similar to those reported in Puerto Rico.

An important issue reported by McMichael et al. (1989) and later confirmed by Aliaumea et al. (2000) is that snook growth varied with spawning season; juveniles less than 100 days old recruited during the wet season had a significantly higher growth rate (0.67 mm/d) than individuals recruited in the dry season (0.41 mm/d). These differences have to be taken into consideration if further studies on juvenile snooks are conducted in Mexico. More research is needed in this area to determine better estimates of growth rate and age of gonadal differentiation.

We were not able to assess the effects of temperature manipulation or estradiol-17 β administration on the timing and pattern of gonadal sex differentiation in common snook. Snook susceptibility to bacterial and fungal infections in captivity complicates considerably the implementation of research using wild fish. We were able to successfully wean the fish (i.e. changing from feeding live to dry food). We are currently growing a few fish that survived the E2 treatments and expect that valuable preliminary information on sex inversion will be generated shortly.

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Table 1: Mean \pm standard error of water quality parameters measured during experiment 2a.

	17.5 °C	22.5 °C	27.5 °C	32.5 °C
T °C \pm SE	17.34 \pm 0.05 °C	22.57 \pm 0.03 °C	27.41 \pm 0.05 °C	32.30 \pm 0.03 °C
DO \pm SE	10.23 \pm 0.14 mg/L	8.71 \pm 0.13 mg/L	8.00 \pm 0.11 mg/L	7.37 \pm 0.11 mg/L
pH \pm SE	7.9 \pm 0.03 u. i	7.7 \pm 0.02 u. i.	7.75 \pm 0.01 u.i.	7.69 \pm 0.02 u. i.
AMMONIA \pm SE	2.6 \pm 0.29 mg/L	2.5 \pm 0.17 mg/L	2.77 \pm 0.19 mg/L	2.52 \pm 0.21 mg/L
NITRATES \pm SE	0.50 \pm 0.07 mg/L	0.67 \pm 0.09 mg/L	0.50 \pm 0.06 mg/L	0.49 \pm 0.06 mg/L
NITRITES \pm SE	0.19 \pm 0.09 mg/L	0.19 \pm 0.07 mg/L	0.31 \pm 0.06 mg/L	0.25 \pm 0.04 mg/L
SALINITY	10 ppm	10 ppm	10 ppm	10 ppm

Table 2. Mean \pm standard error of water quality parameters measured during experiment 2b.

	MIN	MAX	MEAN \pm SE
T °C \pm SE	28.2 °C	32.1 °C	30.2 \pm 0.14 °C
DO \pm SE	6.8 u. i.	7.5 u. i.	7.07 \pm 0.02 u. i.
pH \pm SE	5.3 mg/L	7.45 mg/L	6.52 \pm 0.07 mg/L
AMMONIA \pm SE	0.06 mg/L	0.12 mg/L	0.09 \pm 0.01 mg/L
NITRATES \pm SE	0.23 mg/L	0.72 mg/L	0.54 \pm 0.03 mg/L
NITRITES \pm SE	0.079 mg/L	0.115 mg/L	0.084 \pm 0.01 mg/L
SALINITY	10 ppm	10 ppm	10 ppm

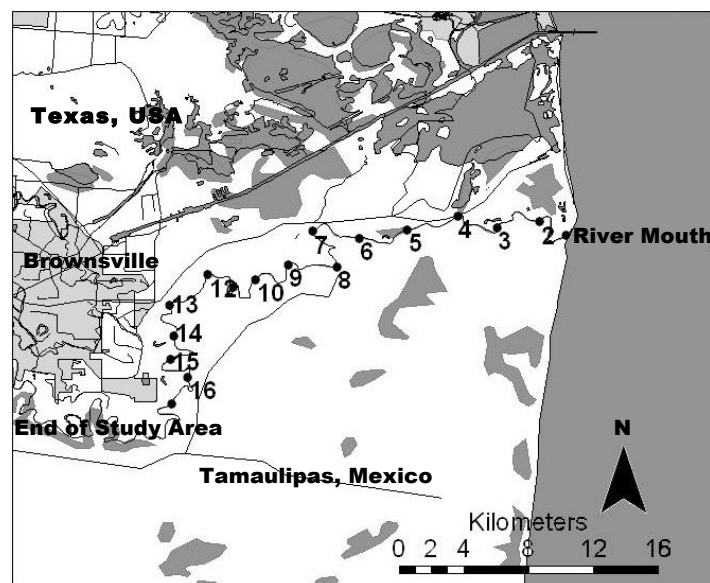


Figure 1. The lower 51.5 km of the Rio Grande/Rio Bravo along the USA-Mexico border, including hydrology (dark grey) and urban (light grey; Brownsville) areas. This study included an assessment of habitat quality (under different funding sponsorship) and for this purpose the study area was divided into 16 sections of 3.2 km each. Numbered points along the river indicate the beginning of each river section (3.2 km) from the mouth to the end of the study area (section 1 extends from the river mouth to point 2 and section 16 extends from point 16 to end of the study area).

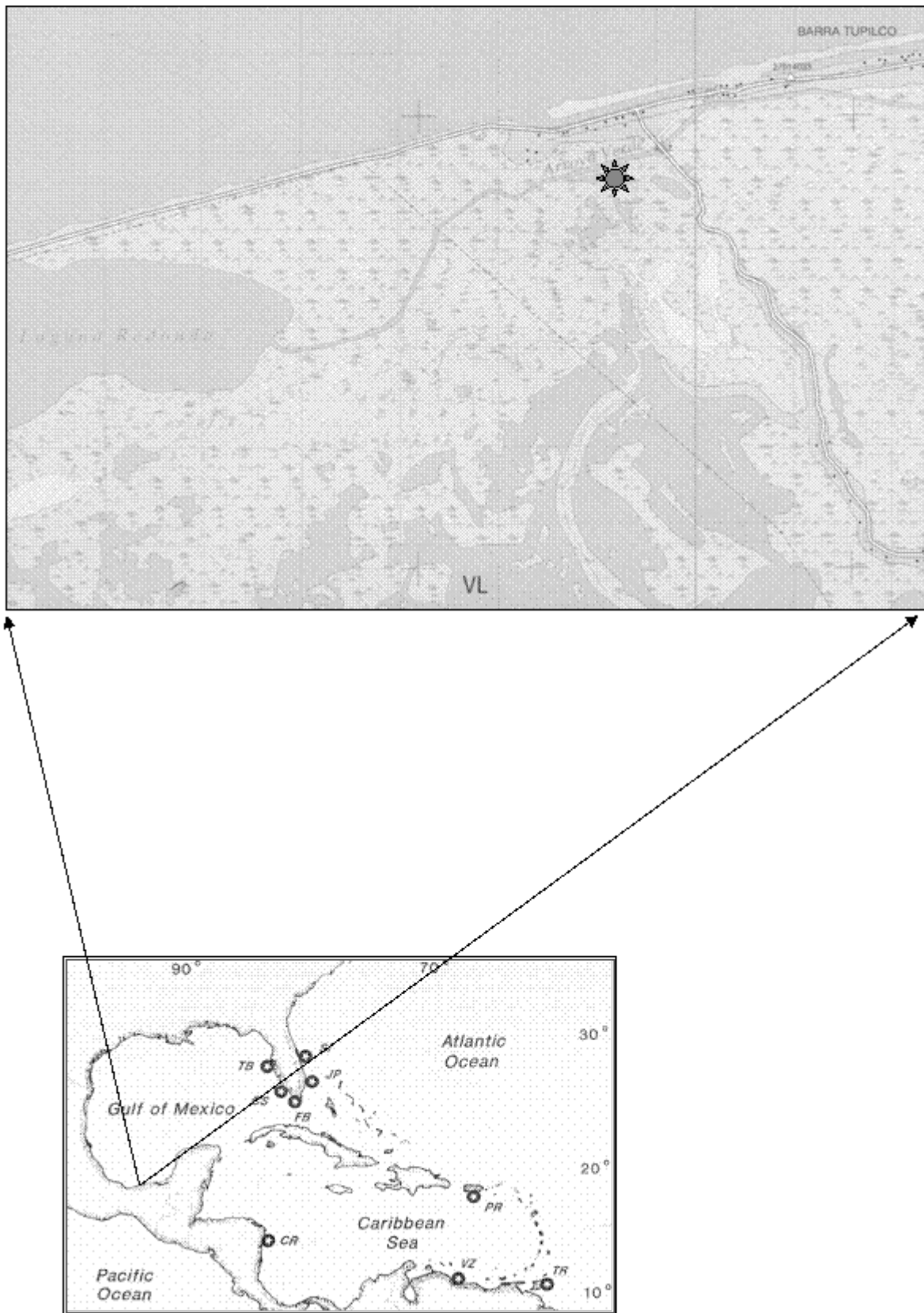


Figure 2. Map of the sampling site. Star indicates location of the mangrove area where snooks were collected in Tabasco. This area is located at the municipality of Paraíso.

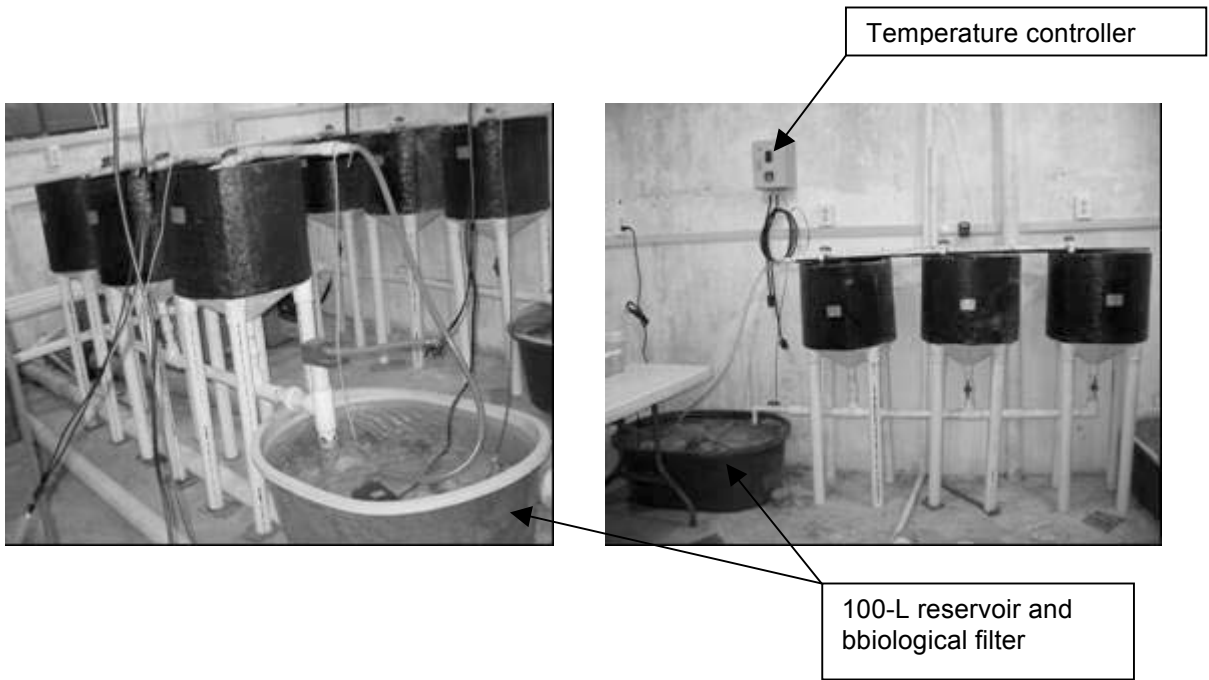


Figure 3. Recirculating systems used in experiment 2a. *Manipulation of water temperature.*



Figure 4. Recirculating systems used in experiment 2b. *Administration of estradiol-17 β .*

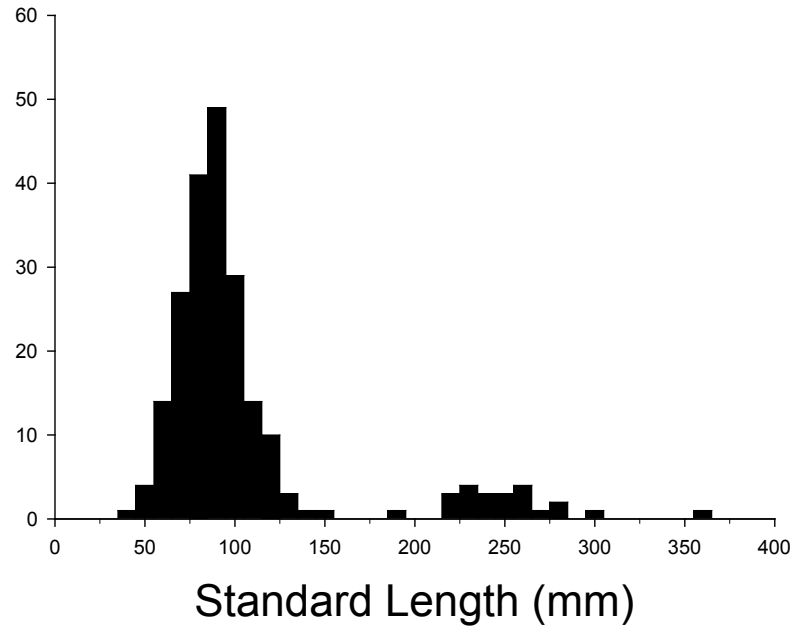


Figure 5. Length-frequency histogram of all common snook captured in the lower 51.5 km of the Rio Grande/Rio Bravo (Texas/Mexico) using trawl, castnet and electrofisher during January-March 2006.

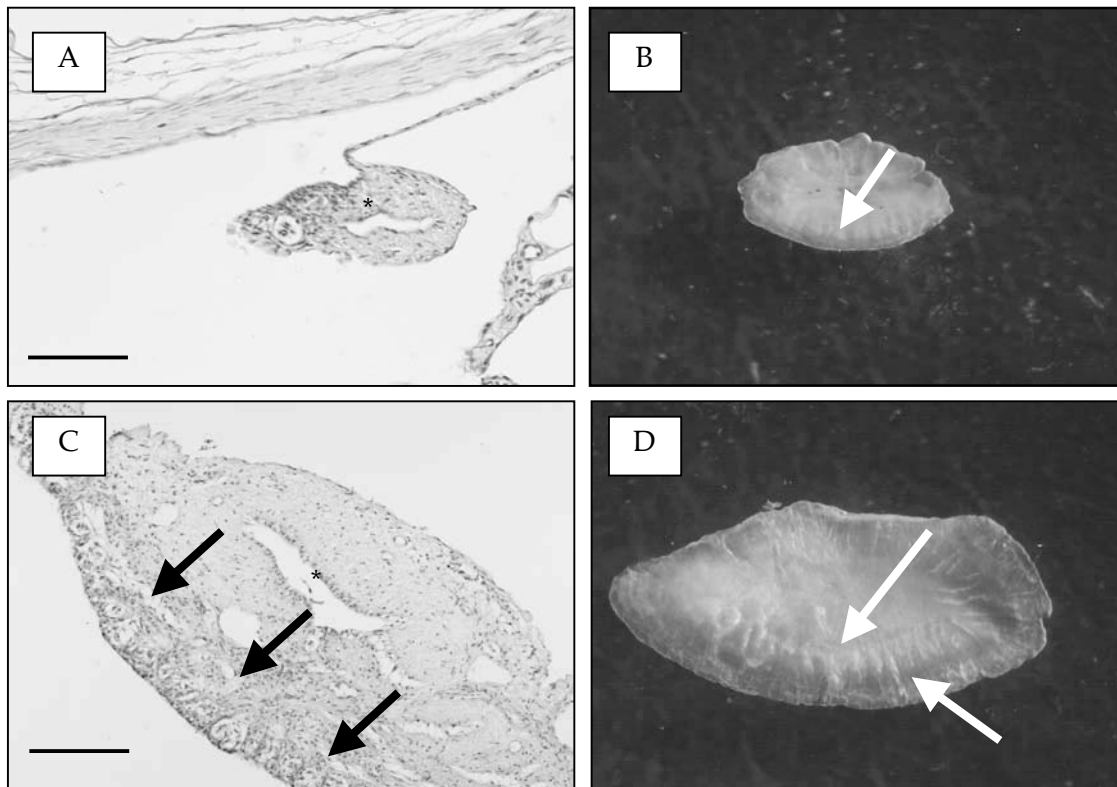


Figure 6. Gonad cross section (left) and whole sagittal otolith (right) from an age-1 (A and C) and an age-2 (B and D) common snook captured in the lower 51.5 km of the Rio Grande/Rio Bravo (Texas/Mexico) during January-March 2006. Asterisks indicate the sperm ducts, black arrows indicate germinal epithelium and white arrows indicate annuli.

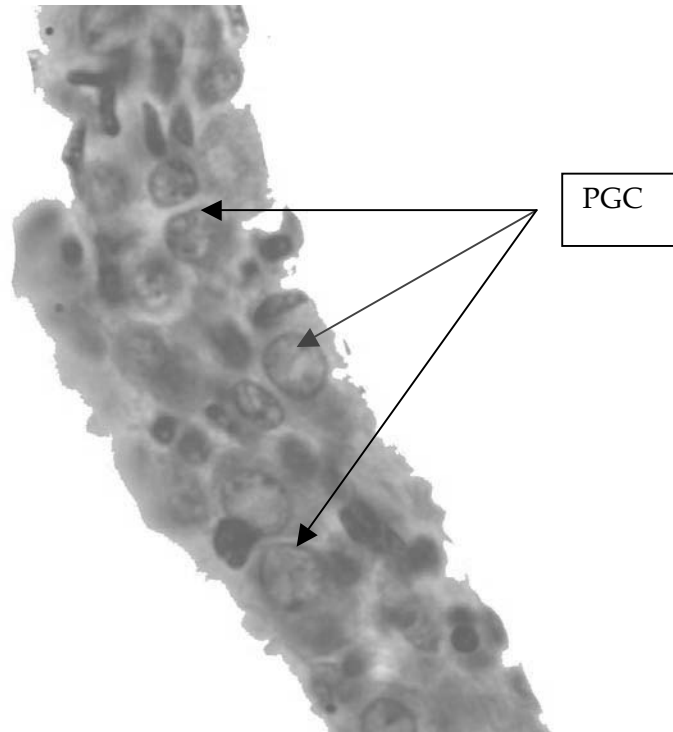


Figure 7. Undifferentiated gonad from a *C. undecimalis* juvenile. Primordial Germ Cells (PGC) are visible. Sample stained with hematoxylin-eosin (50X).

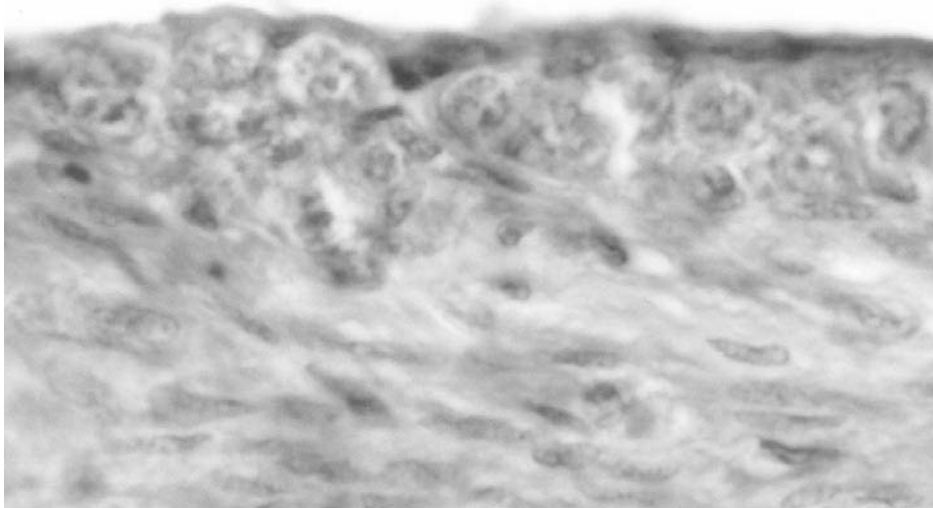


Figure 8. Early testis of *C. undecimalis*. Spermatogonia (SG) are grouped in clusters. Sample stained with hematoxylin-eosin (50X).

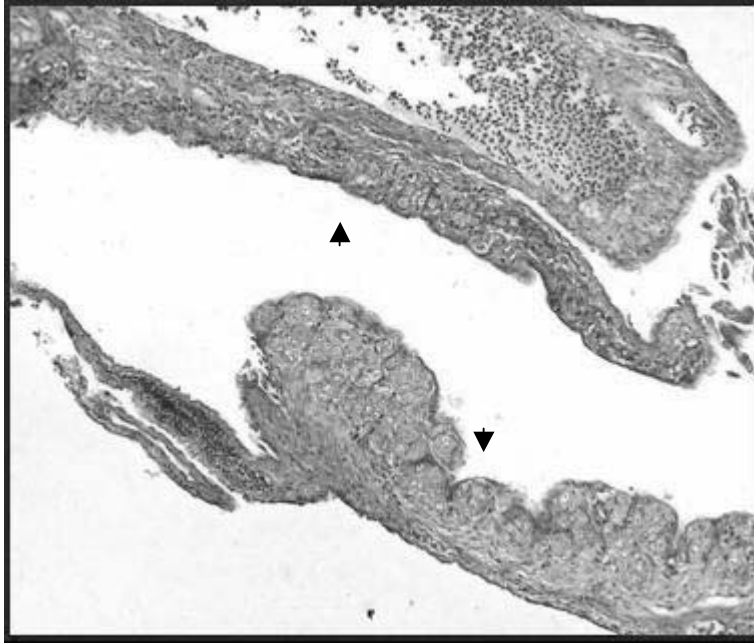


Figure 9. Advanced testicular development of *Centropomus undecimalis* (↑↓). Sample stained with hematoxylin-eosin (50X).

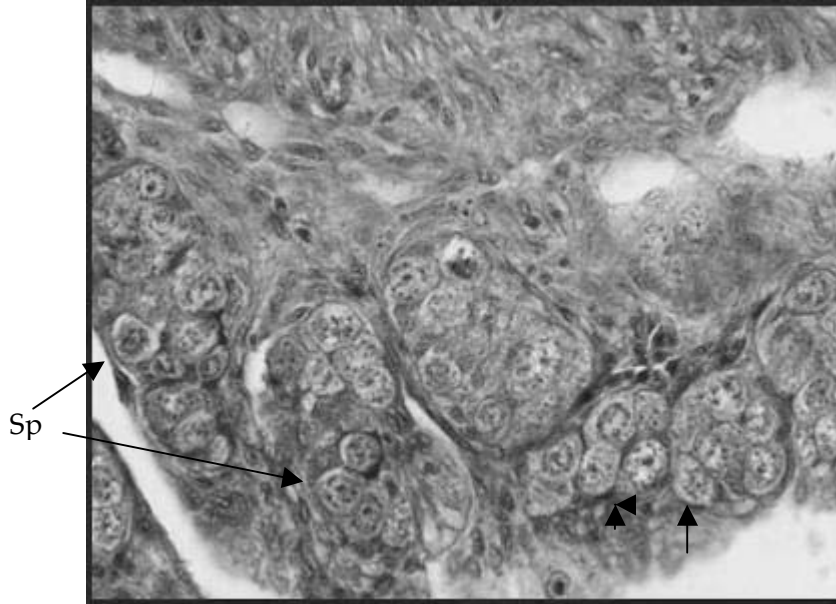


Figure 10. Advanced testis development of *Centropomus undecimalis* (↑↓); Spermatogonia (sp), Sertoli cells (↑). Sample stained with hematoxylin-eosin (200X).

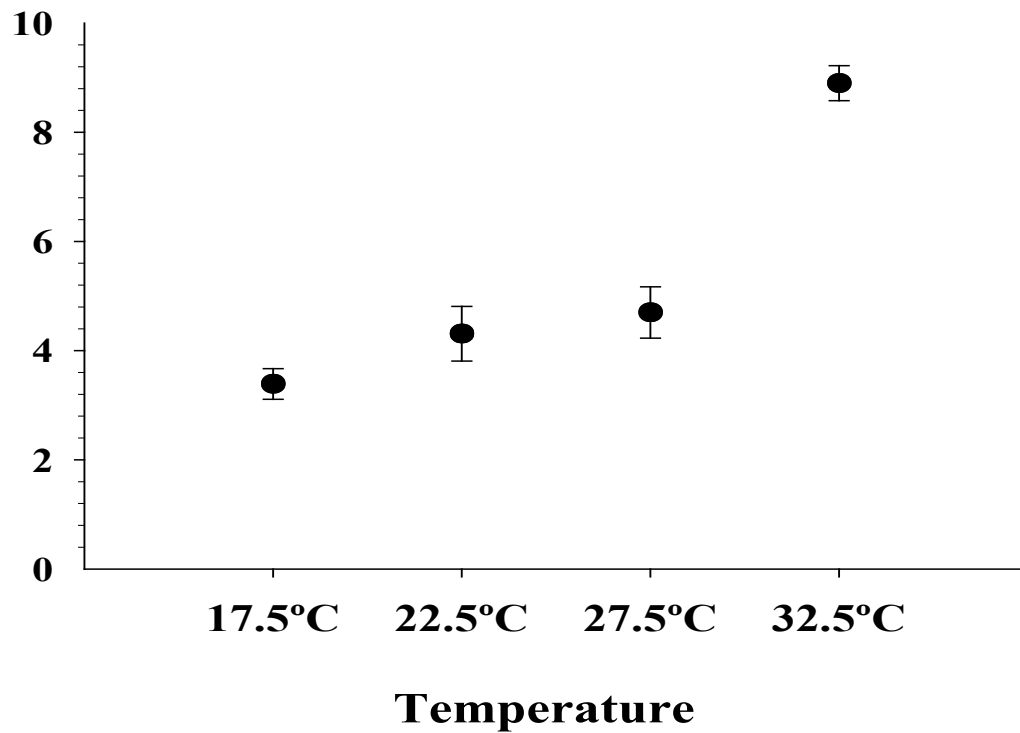
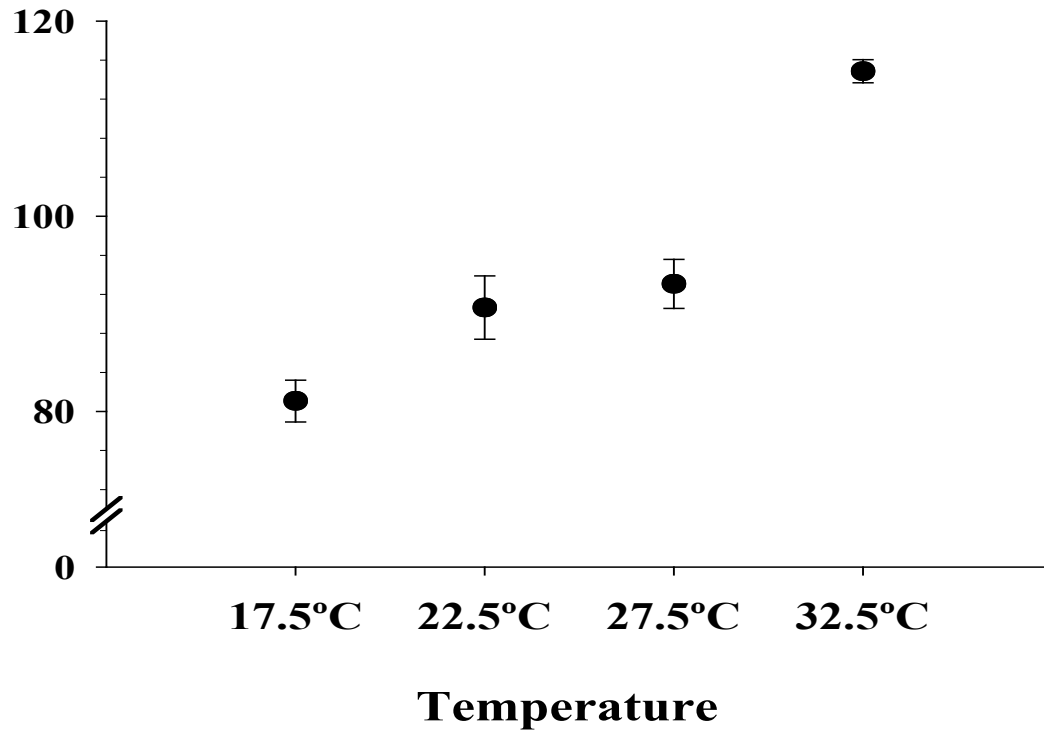


Figure 11. Total length (A) and weight (B) of *C. undecimalis* kept under different temperatures. Different letters indicate Statistical significant differences ($P < 0.05$).

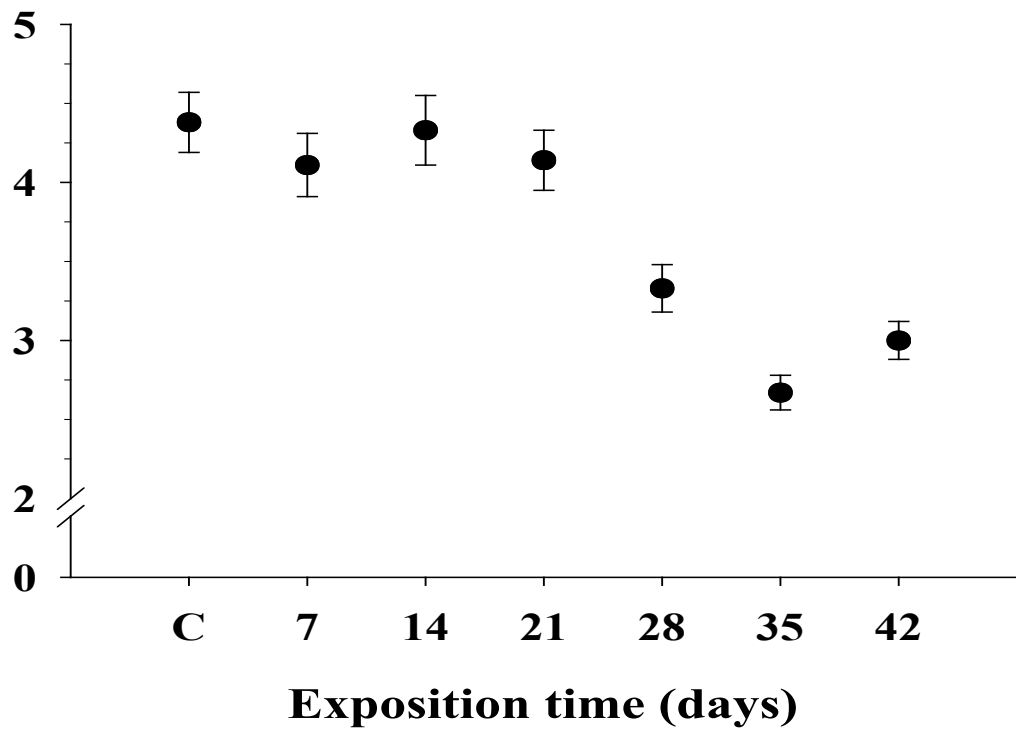
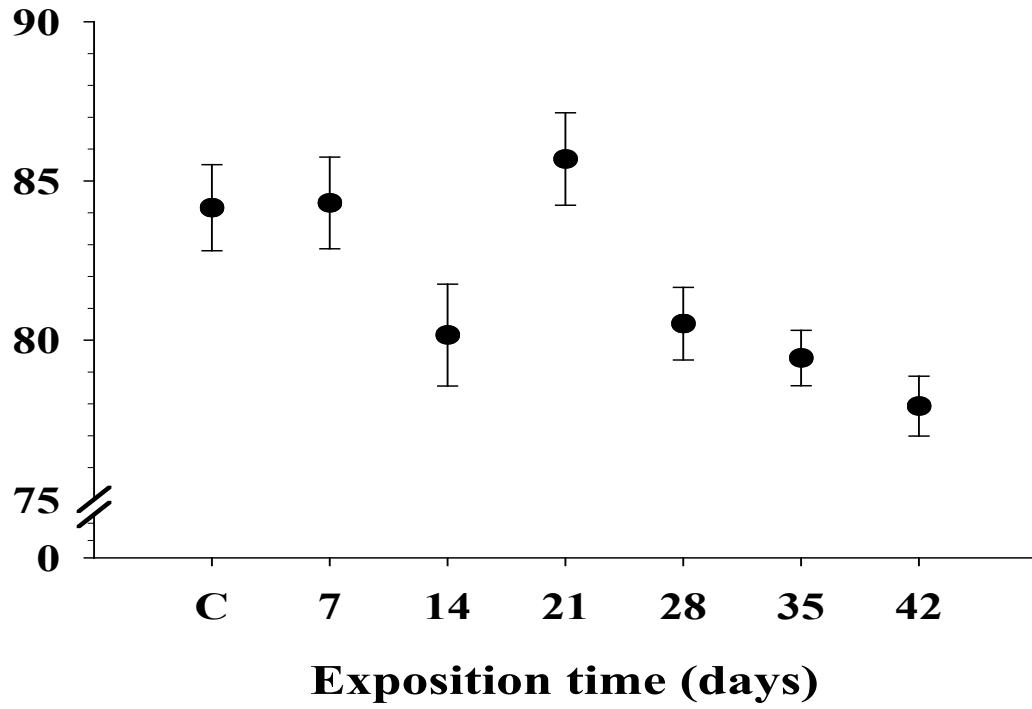


Figure 12. Total length (A) and weight (B) of *C. undecimalis* fed with Estradiol (E2) for different times. Fish in the control group (C) were fed without E2. Different letters indicate statistical significant differences ($P < 0.05$).

KENYA CAPACITY BUILDING: STUDENT RESEARCH AND THESIS SUPPORT

Twelfth Work Plan, Seedstock Development & Availability 5 (12SDA5)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

In this investigation the OSU/Kenya Project provided support for students pursuing aquaculture studies at Moi University, Eldoret, Kenya during the 2005-2006 academic year. This included two one-year scholarships for two students working on Master of Science (MSc) degrees as well as short-term stipends for three undergraduate students working on their senior projects. The work was conducted primarily at Moi University, Eldoret. Support was also provided for one of our previous graduate students to present research results at the "AQUA 2006" conference in Florence, Italy.

Research topics undertaken by the two new graduate students included work on 1) the fecundity and energetics of tilapia (*Oreochromis niloticus*) brooders conditioned under different feeding regimes and 2) yields of Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) reared together in different stocking ratios. Both students have finished their coursework and the research phase of their programs and are currently writing their theses, with the expectation that one will have earned her degree by December 2007 while the other one will complete it later; by June 2008.

Graduate student Victoria Boit traveled to Florence, Italy, to participate in "AQUA 2006" from 9-13 May, 2006, where she presented the results of her research in the CRSP session on Saturday, May 13. Her presentation was entitled "Effects of three feeding regimes and two light regimes on the growth and survival of African catfish *Clarias gariepinus* fry in aquaria." Victoria has since submitted her thesis to the Moi University Graduate School for approval, and her defense was held on 30th May 2007. She has submitted her final copy and will graduate in December 2007.

INTRODUCTION

Since the mid 1990s, fish farming has been undergoing a major revival in Kenya. After several decades during which many previously constructed ponds fell into disuse, renewed efforts by organizations such as the Kenya Fisheries Department, the FAO, the Belgian Survival Fund, and the Aquaculture CRSP to conduct research and disseminate results about appropriate practices, farmers are now realizing that fish farming can be a profitable enterprise. This has resulted in the revival of some previously abandoned ponds, the construction of numerous new ponds, and a renewed enthusiasm for fish farming among farmers. While some farming of rainbow trout (*Oncorhynchus mykiss*) is practiced in the cool highlands around Mt. Kenya and Mt. Elgon, the primary species cultured in most of the country are the Nile tilapia (*Oreochromis niloticus*) and the African catfish (*Clarias gariepinus*).

Most of the research conducted in the last decade by the Aquaculture CRSP has focused on basic pond culture techniques (appropriate fertilization and feeding regimes) for tilapia grown in static-water ponds, but a growing interest in the culture of the African catfish and production of catfish

fingerlings has led, in recent years, to research focused on improving the survival of catfish fry reared to the fingerling stage. There are many remaining questions regarding the culture of both tilapia and catfish, two of which have been the focus of this additional research.

For example, it is not known whether the standard pond fertilization regime practiced in production ponds in Kenya is appropriate for the conditioning of broodfish for spawning. One of our lines of investigation has therefore been to examine variations to the standard fertilization regime to determine if broodfish conditioning can be improved.

One of the standard recommendations for tilapia culture in Kenya has been to stock catfish with the tilapia at a rate of 5-10% of the number of tilapia stocked. This recommendation has been made primarily as a way to control the unwanted reproduction that usually occurs in tilapia ponds, but farmers do also realize the benefit of a second species being produced for sale or consumption. This remains a significant problem for tilapia farmers in Kenya because there are as yet no producers of sex-reversed fingerlings in the country, so farmers either rely on hand-sexed all-male populations or must resort to simply stocking mixed-sex fingerlings; in either case reproduction early in the culture period often becomes a problem. In this investigation we therefore undertook a study of various tilapia/catfish stocking ratios to determine if a ratio other than the standard recommendation would be more advantageous in terms of tilapia or catfish yields.

In the past we have not had sufficient funds budgeted to support student travel to conferences to present the results of their thesis research. In this investigation we, therefore budgeted funds to support travel by one of our students to present results at the "AQUA 2006" world conference in Florence, Italy. We also provided stipend support for three undergraduate students working in aquaculture at Moi University.

OBJECTIVES

The objectives of this investigation were:

- To provide support for research and thesis work of two current graduate students pursuing aquaculture studies at Moi University, Kenya
- To provide stipend support for three undergraduate aquaculture students working on their senior projects at Moi University, Eldoret, Kenya, or Sagana Fish Farm, Sagana, Kenya.
- To provide support for one graduate student to present research results at the "AQUA 2006" conference in Florence, Italy.

MATERIALS AND METHODS

Graduate Student Support

Research and Thesis Work at Moi University: Two master's degree (MSc) candidates, namely Elizabeth Nyanchiri and James Mugo, already enrolled at Moi University (Department of Fisheries and Aquatic Sciences) (MU), were selected to receive one year of scholarship support. They were selected based on their academic qualifications and the relevance of their proposed research to the goals of the Aquaculture CRSP. Research topics were selected and research conducted under the supervision of Drs. Charles Ngugi (Moi University) and James Bowman (Oregon State University). Their coursework and research was conducted entirely on the Chepkoilel Campus of Moi University and at the Moi University Fish Farm, with day-to-day supervision by Dr. Ngugi between September 2005 and June 2007.

In the first experiment, done by Ms. Elizabeth Nyanchiri, a 182-day trial of different stocking ratios for mixed-sex tilapia:catfish polyculture was conducted in small (100m²) earthen ponds at Moi University, Eldoret, Kenya. Tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) were stocked at three stocking ratios of 2:1, 6:1, and 19:1 based on wet weight (i.e., the ratios were the treatments). Each treatment and control was replicated thrice, hence 12 ponds of 100 m² each were used.

For Mr. James Mugo Bundi's work, a 180-day study was designed to investigate the effect of varying feed protein levels on gonad maturation, fish size at first maturation, and fecundity of Nile tilapia (*Oreochromis niloticus*) reared in earthen ponds. Feeds with different protein levels (15%, 20%, and 25% crude protein) were applied in replicates to 12 completely randomized earthen ponds pre-stocked with 4 fingerlings per m² (average weight, 2 g). After 180 days, visual classifications of gonadal developmental stage, gonadal weight, and gonado-somatic index (GSI) were used as indicators of gonadal maturation. The size of fish was determined by measuring length and weight, while fecundity was by direct counting of the eggs. Data was subjected to one way analysis of variance (ANOVA), and also a non-parametric test (Chi-square (χ^2)).

Findings of this study will be used as the basis of formulating feed that will delay gonadal maturation, increase size at first maturation, and not change fecundity of Nile tilapia, thus increasing pond production.

Participation in AQUA 2006, Florence, Italy: Ms. Victoria Boit, whose MSc work was supported under a previous CRSP investigation, was selected to present her work on the "Effects of three feeding regimes and two light regimes on the growth and survival of African catfish *Clarias gariepinus* fry in aquaria" at the "AQUA 2006" conference in Florence, Italy. Drs. Ngugi and Bowman assisted her in preparing her results in a format suitable for the conference. Support for her travel (airfare, per diem, and lodging) was provided through the MU budget for this investigation.

Undergraduate Stipends

Short-term stipends were provided for two undergraduate students in the Department of Fisheries and Aquatic Sciences at Moi University. Students were selected by Head of Department and CRSP PI, Dr. Charles Ngugi, who also supervised the work of these students.

The following students were attached at the fish farm and received support from CRSP: Veronica Wambugu and Samson Ochieng.

RESULTS

Graduate Student Support

Research and Thesis Work at Moi University: Two students, Mr. James Mugo Bundi and Ms. Elizabeth Mwikalia Nyanchiri, were selected to receive scholarship support for the second year of their graduate programs at MU. James Bundi's research was on the fecundity and energetics of tilapia (*Oreochromis niloticus*) brooders conditioned under different feeding regimes, while Ms. Nyanchiri focused on the effects of different tilapia (*Oreochromis niloticus*) and catfish (*Clarias gariepinus*) stocking ratios on the yields of these two species in ponds. Synopses of their respective research efforts are given here; details can be found in their completed theses, which will be submitted and kept on file at the CRSP Program Management Office when completed and approved by Moi University.

Preliminary results of Ms. Nyanchiri's work were presented as a poster in the WAS Conference, held in Florence Italy from 9th to 13th May 2006. Further, Ms. Nyanchiri's work on "Stocking ratios of Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) and their effects on yield and profitability in earthen ponds" was presented by Dr. Ngugi at the "AQUA 2006" conference in San Antonio, Texas, USA. Drs. Ngugi and Bowman worked with Ms. Nyanchiri in preparing her results in a format suitable for the conference.

Ms. Nyanchiri reported that the mean final weight for tilapia in all the treatments ranged from 162.63 to 196.32 g. There was a significant difference in the mean final weight for tilapia between the treatments at $P < 0.05$, $F = 160.23$ and $d = 3$. Mean final weight of African catfish in all the treatments ranged from 189.92 to 192.42 g with no significant difference in the mean final weights among the treatments at $P > 0.05$, $F = 0.42$ and $d = 2$. However, net yields among the treatments were

significantly different ($p < 0.05$), with Treatment 1 having the highest yield. The total tilapia yield ranged from 2.19 to 3.09 ton/ha/yr (Table 3), while that of catfish ranged between 0.38 and 2.21 ton/ha/yr.

Treatment 1 (2:1 stocking ratio) produced the highest total revenue while the control produced the least. Total variable costs ranged between Ksh260,735.80 to Ksh218,495.80, with Treatment 1 having the highest and the control having the lowest. However, total fixed costs in the full-cost enterprise budgets were the same for the four different treatments. Break-even price above total costs ranged from Ksh 83.23 to 139.84 (Table 11) with the control having the highest and Treatment 1 the lowest. Treatment 1 had the highest net income change (Ksh 236,760) while Treatment 3 (19:1 ratio) had the lowest (Ksh 37,296). However, high a return on investment was recorded in all the polyculture treatments as compared to the Nile tilapia monoculture. Survival rate among the treatments was not significantly ($P > 0.05$) different, ranging from 81.00 to 83.00 for both species.

James Mugo Bundi is still running his thesis experiment, which will be finished by the end of June 2007. Preliminary results will therefore appear after June 2007 in his first thesis draft.

Participation in AQUA 2006, Florence, Italy: Ms. Victoria Boit joined other CRSP participants in Florence, Italy, for the "AQUA 2006" conference (9-13 May, 2006), where she successfully presented her work on the "Effects of three feeding regimes and two light regimes on the growth and survival of African catfish *Clarias gariepinus* fry in aquaria." Her presentation was part of the CRSP session on Saturday morning, May 13th. Her presentation was very well done and well received. Ms. Boit gained valuable insights into the world of aquaculture research, presentation of results, and networking at the international level.

Undergraduate Stipends

Short-term (four months each) stipends were provided for two undergraduate students, Veronica Wambugu and Samson Ochieng, in the Department of Fisheries and Aquatic Sciences at Moi University. Veronica Wambugu worked in the area of tilapia pond water quality management, whereas Samson Ochieng looked at feeding live feeds to African catfish larvae held in round tanks held in a green house and assessing their survival under raised and controlled temperatures that favour catfish larvae. The work of these students, which formed part of their field attachment course, was supervised by Charles Ngugi and James Mugo (graduate student).

QUANTIFIED ANTICIPATED BENEFITS

Two additional graduate students received training, gaining valuable experience in aquaculture research methods, pond management, and various aspects of tilapia and catfish breeding and culture. New information is being obtained on the fecundity and energetics of tilapia brooders conditioned in static ponds under different feeding regimes, which should help producers improve tilapia fingerling production in the future. New information has been obtained on the effects of different stocking density combinations on the yields of tilapia and catfish, which, when disseminated to producers, should help them increase yields from their polyculture ponds. One other student gained valuable experience in preparing and presenting the results of their thesis research at a major international conference. These are all promising young students, who we expect will go on to serve the public, whether through attachment at the University, in the Fisheries Department or other related Government agency, or through private enterprise.

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IMPROVEMENT OF TILAPIA FINGERLING PRODUCTION AND AVAILABILITY IN CENTRAL AMERICA

Twelfth Work Plan, Seedstock Development & Availability 6 (12SDA6)

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

Locally generated research results are more relevant when technicians and extension agents are discussing production options with farmers. Both Nile (*Oreochromis niloticus*) and red tilapia strains (*O. sp.*) are cultured in Central America. Each genetic line has several advantages and disadvantages for the farmer to consider in selecting a fish for culture. We compared the reproduction of Nile and red tilapia in two environments: 7.5 x 2.0 x 1.0 m concrete tanks and 200 m² earthen ponds in Honduras. All experimental units were covered with predator netting (25 mm mesh) and the water in the concrete tanks was continuously aerated. Each earthen pond was divided into two 100 m² compartments by fiber-glass window screening (1.5 mm mesh) supported in the vertical position by 12 mm mesh Vexar plastic netting and wooden stakes. A similar biomass of adult females was stocked in each of four pond compartments (23.2 kg / compartment) and each of four tanks (6.5 kg / tank) with a 3♀:1♂ sex ratio of adult fish. Production cycles were of 20 and 30 days duration for the tanks and pond compartments, respectively. We repeated the trial in the tanks and performed three replicates in the ponds. The mean total production of tilapia fry/m² was significantly greater from the concrete tanks in comparison with the ponds. We harvested an average of 38,700 and 23,550 fry from each concrete tank, and 117,153 and 63,361 fry from each pond compartment, for the Nile and red tilapia, respectively. Survival of the Nile tilapia fry (85%) was significantly greater than for the red tilapia (58%) during the subsequent 30-day hormone treatment period. More adult red tilapia died than Nile fish during these trials. Overall mortality was significantly greater when the adult fish of both lines were stocked and managed in the earthen ponds compared to the concrete tanks.

INTRODUCTION

Tilapia was introduced to Central America in 1954 by FAO specialists (Meyer 1989) visiting the region on a technical mission. Today the commercial culture of tilapia and export of fresh fillets is important in several regional countries. Additionally, there are many small and medium-scale farms throughout Central America producing tilapia for local markets or for export of whole fish to neighboring countries (Triminio *et al.* 2007).

In general, tilapia is an ideal candidate for culture due to its resistance to handling stress and the excellent color, texture and flavor of its flesh. Tilapia is an omnivorous filter feeder. These fish are efficient at ingesting phytoplankton, periphyton, detritus, fecal material, insect larvae and adults, and other food items available in the aquatic environment. They also readily accept artificial feeds formulated primarily with basic grains and agricultural by-products.

Tilapia reproduces on the farm without any special cultural practices, sophisticated laboratory facilities or specially trained personnel. Their ability to reproduce spontaneously in ponds and other water containers is considered a possible defect among their multiple advantageous characteristics or attributes (Teichert-Coddington *et al.* 1997).

In spite of the ease to reproduce these fish on the farm, the lack of adequate amounts of quality seed has been a factor limiting the expansion of tilapia culture in many parts of the world (Meyer, 1988; Popma and Green, 1990; Little et al., 2000). The several tilapia species cultured are generally of low fecundity and the brood fish tend to spawn at irregular intervals.

Most fish farmers in Central America culture either the Nile (*Oreochromis niloticus*) or red varieties of tilapia (*O. sp.*) (Aceituno et al. 1997; Tave et al. 1989a; Green 1999). There are several important differences between these fish (Lovshin 2000).

Both the Nile and red varieties are considered resistant to pathogens, and hardy fish. Tilapia can survive and gain weight efficiently in conditions of low dissolved oxygen, elevated concentrations of ammonia and highly turbid waters. The Nile fish has a blue or grayish color to the body and fins (Tave et al. 1989b), and a robust body. Their natural coloration provides protection in the water from avian and other predators.

The red varieties of tilapia are derived from the Mozambique or Java tilapia (*O. mossambicus*) which is relatively slow growing and reproduces at a smaller size and younger age than most other tilapia lines. The red tilapia adapts well to saline and brackish water conditions and has a growth rate similar to the Nile fish (Stickney 1986).

The Jamaican red tilapia was introduced to Honduras in the early 1990s. These fish have been crossed with additional species and their present pedigree is confusing. Green (1999) stated that the red tilapia fish in Honduras are hybrids containing a mixture of genetic material from *O. mossambicus*, *O. urolepis hornorum*, *O. aureus* and *O. niloticus*.

The Aquaculture Collaborative Research Support Program (ACRSP) has functioned since 1983 under the basic premise that locally generated research results are more useful and relevant to properly orienting beginning fish farmers throughout the world (Egna et al, 1997, Egna 1997). Since 1999 the efforts of the ACRSP in Central America have focused on improving tilapia seed production and availability in Honduras and neighboring countries (Triminio Meyer et al. 2007).

We compared the reproduction of Nile and red tilapia in concrete tanks and in compartments in earthen ponds on the Aquaculture Station of the Escuela Agrícola Panamericana (EAP) in Honduras.

MATERIALS AND METHODS

The reproduction trials were done in four concrete tanks (7.5 x 2.0 x 1.0 m) and two earthen ponds (20 x 10 x 1 m). Each pond was divided in half by fiber-glass window screening (1 mm mesh) reinforced with 12 mm mesh Vexar™ plastic netting maintained and supported in a vertical position by wooden stakes driven into the bottom. Both netting materials were partially buried in the bottom mud of each pond and anchored in place by bricks placed at 50 cm intervals on each side of the barrier.

The concrete tanks and ponds were covered by predator netting (25 mm mesh). The water in each tank was continuously aerated by three 10 cm long fused silica air diffusers connected to a blower (2.5 HP) via PVC pipe (25 mm diameter).

Adult Nile and red tilapia were stocked into each of the four tanks and each of the four 100 m² pond compartments at 6.5 and 23.2 kg of ♀ biomass, respectively. The average weight of the adult females was in the range of 180 to 230 g. The adult male fish were stocked in both the tanks and pond compartments at a 3♀:1 ♂ sex-ratio. The adult fish were fed at 3% of their biomass per day in the tanks and ponds with a floating pelleted diet containing 28% crude protein.

The trial in the concrete tanks was repeated twice, each time for 20 days, for a total of four repetitions. The 30-day long trial was repeated three times in the pond compartments for a total of six repetitions. All adult fish were rested for a minimum of seven days between trials.

Water temperature and dissolved oxygen levels were monitored in the morning and afternoon hours of each day with an YSI Model 55 polarographic oxygen meter (Yellow Springs Instrument Company, Yellow Springs, Ohio, USA).

Free-swimming fry were captured from the pond compartments every other day using hand nets. The concrete tanks were drained on the final day of each production cycle to collect all fry in a single harvest.

All captured fry were enumerated by visual comparison of populations. One-thousand fry were individually counted into a white plastic dish containing 2 L of water. Additional fry were added to a second identical dish until the populations appeared equal by visual comparison. This procedure was repeated and any remaining fry were counted individually.

The fry from all trails were then sex-reversed (60 mg of 17- α -methyl-testosterone/kg of feed) for 30 days (Popma and Green 1990) in concrete tanks (7.5 x 2.0 y 1.0 m) at a stocking density of 2000/m³. The feed (38% crude protein) for the fry was prepared by grinding and passing thru a fine meshed sieve (0.20 mm), and then offered to the fry in each tank *ad libitum* four times per day.

The analysis of costs was done based on the following premises and values for operating a fish farm in Honduras. The minimum wage for unskilled farm laborers in Honduras is approximately US\$ 160.00 per month. For a semi-skilled or experienced laborer, we used a base salary of US\$ 250.00 and a standard package of social benefits of USD 50.00 per month.

The water pumps had 3.0 and 15.0 hp electrical motors for filling the tanks and ponds, and had estimated pumping rates of 280 and 1100 L/minute, respectively. The blower for aerating the tanks on the Zamorano Station has a 2.5 hp motor. The consumption of electrical current by the motors was estimated using 0.746 kW/hp (Anonymous 2007). The cost of electricity in Honduras varies according to consumption rates and a user classification systems. We applied a value of US\$ 0.11 per kW/h for electrical current consumption by the motors of the water pumps and the air blower.

Depreciation of the tanks and ponds was based on construction costs of US\$ 1000 for each and estimated 10 years of use. The replacement any adult fish that died during the trials was included as a variable cost.

RESULTS

During the several repetitions of the experiment, the water temperatures at the Zamorano Aquaculture Station ranged from 23.8 to 31.5 C, and averaged 28.1 C in the ponds. Water temperatures in the concrete tanks ranged from 24.6 to 30.0 C, with an average of 27.4 C.

Morning dissolved oxygen concentrations were always ≥ 2.9 ppm in the water of the concrete tanks. Low dissolved oxygen levels (≤ 1.0 ppm) were detected in the water of the earthen ponds on several occasions. No dead adult fish were ever observed in the ponds or tanks during the experiment.

Overall fry production averaged 45,129 in the pond compartments and 15,598 in the tanks. Fry production averaged 2.72/m² for Nile tilapia and 1.75/m² for red fish in the two environments. Fry production per m² was greater ($P \leq 0.05$) for the Nile fish compared to the red tilapia by 64 and 47%, in the tank and pond environments, respectively.

The Nile fish produced 85% more fry ($P \leq 0.05$) than the red tilapia in the earthen pond compartments, and 65% more fry when stocked in the concrete tanks (Tables 1 and 2). A greater number of adult red fish died than Nile tilapia adults during the several repetitions of the experiment run over a period of approximately six months. No Nile adults died during the trials in the concrete tanks and rest periods. The loss of Nile adults in the earthen ponds averaged 6% of the fish stocked. All of the dead fish were found in the tanks used for resting the adult fish between the several reproduction trials.

A comparison of the estimated costs for producing Nile and red tilapia fry (≤ 12 mm) in a concrete tank and in an earthen pond is presented in Table 4. Overall the total variable costs to produce these fry averaged US\$ 24.12 in the tanks and US\$ 78.64 in each earthen pond compartment.

The values in Tables 5 and 6 are based on the sex reversal of equal numbers of Nile and red fry in a concrete tanks. Significantly greater numbers of Nile fry were produced both in the concrete tanks and in the earthen ponds, and their better survival rate during sex reversal resulted in greater economic benefits from reproducing the Nile fish (Table 7).

DISCUSSION

The EAP Aquaculture Station is at 750 m above sea level and 14° N latitude. The local temperature regime in the prevalent tropical dry climate (Holderidge, 1979) is moderated by the elevation (MacArthur, 1978). Water temperature has a direct influence on tilapia growth and reproduction (Teichert-Coddington, et al. 1997). The optimum temperature for tilapia reproduction is generally in the range of 25 to 30°C.

The fry production per g of female biomass and per m² per day reported here generally coincide or exceed the values compiled by Green et al. (1997) for fish reproduced in hapas, tanks or earthen ponds and by Quan (2000) for fry produced in earthen ponds, plastic-lined ponds and concrete tanks on a commercial tilapia farm.

The red tilapia is a hybrid containing genes from several species (Tave et al. 1989; Green 1999). The genetic diversity present among the red fish may cause problems or confusion among the adults during pairing and courtship.

The final average weights for the sex-reversed fry from this study (Table 3) are similar to those reared by El-Sayed (2002) and Meyer and Smitherman (1993). In this study the difference in the average final weights for sex-reversed Nile and red fingerlings is attributed to the difference in fingerling survival. The red fish were effectively reared at a lower density due to their higher mortality during the 28-day treatment period. Weight gain is inversely related to tilapia fry stocking density (El-Sayed 2002).

The survival of adult red fish followed a similar pattern with fewer surviving when managed in the earthen ponds. The death of our adult fish was observed during the harvest and draining of the earthen ponds and tanks, and during the rest period between successive trials. An average of 11% of the stocked adult red fish died when harvested from the earthen ponds or during the rest periods.

When ponds are drained some of the fish become stranded in the mud and covered with sediment. Frequently these fish suffer from lesions and injuries that can lead to infection and death. Greater survival of adult fish was observed when Nile tilapia adults were managed for fry production in plastic-lined ponds (92%) and concrete tanks (86%), compared to fish managed in earthen ponds (80%), from a study done on a commercial tilapia farm in Honduras (Quan 2000). Adult Nile tilapia brood fish had similar survival rates when intensively managed in nylon hapas suspended in earthen ponds in Thailand (Little et al. 2000).

The amount of feed utilized and labor costs were greater for producing fry in the ponds in comparison to the concrete tanks. Each production cycle in the ponds was of 30 days duration compared to only 20-day cycles used in managing the fish in the concrete tanks. Labor costs were higher for managing the fish in ponds due to the greater number of adult fish stocked and the harvest of a greater number of fry.

Due to the lower mortality of the adult fish and greater numbers of fry harvested, the production costs for Nile tilapia were much less than for the red fry.

The difference in income generated from the reproduction and fingerling sales with Nile and red tilapia is due in large part to the difference in the observed survival rates between Nile (85.1%) and red fry (58.0%) during the 28-day treatment period.

Sex-reversed red tilapia fingerlings generally are offered for sale at a higher price than similar Nile tilapia fingerlings (Aceituno *et al.* 1997). Labor and feed costs were higher for the Nile fish due to their greater numbers at harvest and additional time required for handling and counting these fish.

The production and sale of sex reversed tilapia fingerlings in Honduras is a profitable activity (Meyer Triminio, 2007). The net income in USD generated from the production and sale of all-male Nile fingerlings was 8% greater than the income from selling red fry. Our production costs for each 1000 sex reversed fry are lower than those reported by Popma and Green (1990) and Engle (1986). Interestingly, sales prices for tilapia fingerlings have not changed substantially during the past twenty years (Meyer, 1988).

ANTICIPATED BENEFITS

The results of this research done locally will be very useful in discussing production options with beginning and experienced fish farmers from throughout Central America. The results of this experimental work, done in 2005 and 2006, have been incorporated into the tilapia reproduction manual published in 2007 for distribution regionally. The manual is used in our ongoing training program with ACRSP funding and from support from the EAP in Honduras. Much of our training effort is directed to NGO extension personnel to take advantage of the potential multiplier effect.

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Table 1. Comparison of fry production from Nile and red tilapia adults managed in 100 m² compartments in earthen ponds in Zamorano, Honduras. The results are averages from a total of six 30-day production cycles. The fry were harvested on alternate days and the ponds drained at the conclusion of each cycle. The values followed by different letters in the same row are significantly different ($P \leq 0.05$).

Parameter	Nile tilapia	Red tilapia
Total number of fry	58,577 a	31,681b
Number of fry/g ♀/cycle	2.5 a	1.7 b
Number of fry/m ² /day	19.5 a	10.6 b
Survival of adult fish	94%	89%

Table 2. Comparison of fry production and survival of Nile and red tilapia adults managed in concrete tanks (7.5 x 2.0 x 1.0 m) in four production cycles in Zamorano, Honduras. All fry were harvested and the tanks drained on day 20 of each cycle. The values followed by different letters in the same row are significantly different ($P \leq 0.05$).

Description	Nile tilapia	Red tilapia
Total number of fry	19,421 a	11,775 b
Number of fry/g ♀/cycle	2.95 a	1.80 b
Number fry/m ² /day	64.7 a	39.2 b
Survival adult fish	100%	90%

Table 3. Final weight and survival of Nile and red tilapia fingerlings at the conclusion of the 28-day sex reversal procedure. The fingerlings were managed in concrete tanks (7.5 x 2.0 y 1.0 m) at a stocking density of 2000/m³ and fed four times a day with a 38% crude protein diet. Amounts are averages for a total of four replicate production cycles. The values followed by different letters in the same row are significantly different ($P \leq 0.05$).

Parameter	Nile tilapia fingerlings	Red tilapia fingerlings
Initial average weight (g)	0.02	0.02
Final weight (g)	0.34a	0.45b
% survival	85.1a	58.0b
Initial density (number/m ³)	2000	2000
Final density (number/m ³)	1702	1160

Table 4. Comparison of the estimated costs (USD) for producing Nile and red tilapia fry (≤ 12 mm) in a concrete tank (7.5 x 2.0 x 1.0 m) or in a 100 m² compartment in an earthen pond, Zamorano, Honduras.

Description	Unit	Unit price	Total value Nile tilapia		Total value red tilapia	
			Tank 20-day cycle	Pond 30-day cycle	Tank 20-day cycle	Pond 30-day cycle
Variable costs:						
Feed (28% crude protein)	kg	0.50	5.40	24.30	5.40	24.30
Labor	Man-hour	1.42	24.12	42.60	22.70	41.18
Electricity (water pump + blower)	kWh	0.11	1.12	3.14	1.12	3.14
Vehicle use	km	0.30	1.20	2.40	1.20	2.40
Replace injured / dead adult fish	Each	1.00	0.00	14.00	8.00	34.00
Fixed costs:						
Depreciation concrete 15 m ³ tank	mo	8.33	8.33	5.81	8.33	5.81
Depreciation water pump + motor	m ³	0.01	0.30	2.00	0.30	2.00
Depreciation air blower	mo	1.20	0.80	---	0.80	---
Estimated Total costs			29.85	78.45	37.85	98.45
Average yield in fry			19,421		11,775	
Average yield of fry				57,577		31,681
Average production cost per fry ≤ 12 mm			0.002	0.002	0.004	0.004
Average production cost/1000 fry ≤ 12 mm			1.87	1.58	3.76	3.51

Table 5. Estimated costs (USD) for producing sex-reversed Nile tilapia fingerlings in a concrete tank (7.5 x 2.0 x 1.0 m), Zamorano, Honduras.

Description	Unit	Quantity	Unit price	Total price
Income:				
Sale of all-male 0.3 g fingerlings	Each	25,530	0.02	510.60
Variable costs:				
Fry ≤12 mm	Each	30,000	0.002	60.00
Feed with hormone 38% crude protein	Kg	23	2.02	46.46
Labor	Man-hour	36	1.42	51.12
Electricity (water pump + blower)	kW/h	2	0.11	0.22
Vehicle use	Km	5	0.30	1.50
Fixed costs:				
Depreciation concrete 15 m ³ tank	Month	1	8.33	8.33
Depreciation water pump + motor	m ³	30	0.01	0.30
Depreciation air blower	Month	1	0.10	0.10
Total estimated costs =				168.03
Cost to produce 1000 fingerlings				
Net Income = Income - Total Costs				
Profit = Net Income/Total Costs x 100				330%

Table 6. Estimated costs (USD) for producing sex-reversed red tilapia fingerlings in a 7.5 x 2.0 x 1.0 m concrete tank, Zamorano, Honduras.

Description	Unit	Quantity	Unit price	Total price
Income:				
Sale of all-male 0.3 g fingerlings	Each	17,400	0.03	522.00
Variable costs:				
Fry ≤ 12 mm	Each	30,000	0.004	120.00
Feed with hormone	Kg	18	2.02	36.36
Labor	Man-hour	36	1.42	51.12
Electricity (water pump + blower)	kW/h	2	0.11	0.22
Fixed costs:				
Depreciation concrete 15 m ³ tank	Month	1	8.33	8.33
Depreciation water pump + motor	m ³	30	0.01	0.30
Depreciation air blower	Month	1	0.10	0.10
Total costs =				216.43
Cost to produce 1000 fingerlings				
Net Income = Income - Total Costs =				
Profit = Net Income/Total Costs x 100 =				

Table 7. Comparison of the relative numbers and costs (USD) for producing Nile and red tilapia sex reversed fingerlings in Zamorano, Honduras.

Description	Nile tilapia fingerlings	Red tilapia fingerlings
Fry produced from 100 m ² pond	57, 577	31,681
Number of sex reversed fingerlings	48,998	18,375
Total Estimated Production Costs	228.33	168.68
Estimated Gross Income	979.76	551.25
Net Income (GI – TPC)	751.43	382.57
Net Income as % of Total Costs	325	227

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

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Final Report

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ABSTRACT

Colossoma macropomum (black pacu, “gamitana”) and *Piaractus brachypomus* (red pacu, “paco”) are high-value foodfish species native to the Amazon Basin. Natural supplies of these fish cannot meet market demand and aquaculture production is intensifying. Standard energy sources in prepared fish diets such as wheat are not economical in the Amazon region, and greater use of native feedstuffs as energy sources is desired. However, there is little research to document the suitability of alternative feedstuffs as energy sources for Characids. We conducted two separate feeding trials to determine the effects of a control diet (containing wheat) versus diets with one of three native Amazonian plant feedstuffs on the performance of *C. macropomum* (Trial 1) and *P. brachypomus* (Trial 2). The native feedstuffs were pijuayo (*Bactris gasipaes*), plátano (*Musa paradisiaca*), and yucca (*Manihot sculenta*), which are all widespread in the Amazon region. Diets were formulated to contain similar amounts of total protein and energy and differed only in the test feedstuff (wheat, pijuayo, platano or yucca) being evaluated primarily as an energy source. Gamitana (22.5 ± 0.03 g initially) or paco (2.56 ± 0.01 g initially) in 4 (trial 1) or 3 (trial 2) tanks per diet were fed one of seven practical diets containing 30% wheat bran (control), cooked or uncooked pijuayo, cooked or uncooked plantain, or cooked or uncooked yucca. Fish were fed the diets to satiation twice daily for 12 weeks. Weight gain (g), feed conversion ratio (FCR), liver glycogen and dry matter, hematology (hematocrit, hemoglobin, and mean corpuscular hemoglobin concentration), and immune parameters (lysozyme and alternative complement activity) were measured to assess diet effects. Weight gain, FCR, survival, and alternative complement activity did not differ by diet for either species. In addition, lysozyme (measured only in paco) did not differ by diet. Hepatosomatic index, liver glycogen, and some of the hematological parameters were affected by diet, but the effects were not consistently associated either with the type of feedstuff or the the form (cooked or uncooked). The effects also were different for the two species, but the gamitana were 10 times larger than the paco initially, so the effects of fish size and species could not be separated. In paco, the cooked yucca and cooked plantain resulted in higher concentrations of hepatic glycogen indicating that cooking increased the available energy of these feedstuffs. Cooking had no effect on hepatic glycogen accumulation in *Colossoma* fed any of the feedstuffs, indicating that cooked feedstuffs did not contain more available energy than uncooked feedstuffs for this species. However, relative to wheat bran all of the feedstuffs tested were effective energy sources for *C. macropomum* and *P. brachypomus* and increased use of pijuayo, plátano, and yucca may reduce diet cost and enhance sustainability of Characid culture in Amazonia.

INTRODUCTION

Colossoma macropomum (black pacu, “gamitana”) and *Piaractus brachypomus* (red pacu, “paco”) are high-value foodfish species native to the Amazon Basin. Natural supplies of these fish cannot meet market demand and aquaculture production is intensifying. However, there are no formulated diets based on the specific nutrient requirements of these species (Cantelmo et al., 1986; Fracalossi, 2002). Their natural diets are rich in plant products ((Kubitzki and Ziburski, 1993; Araujo-Lima and Goulding, 1997) and many Amazonian plant feedstuffs may be suitable for inclusion in practical diets for Characids. Some native ingredients have been used in feeds produced on-farm, but there is scant research-based information on their efficacy as fish-feed ingredients compared to more typical products such as wheat. Furthermore, wheat and possibly other grain products that are standard in diets of warmwater omnivorous fishes in the US are costly and difficult to obtain in the Amazon region. Therefore, native plant feedstuffs should be investigated further for their potential to supply the dietary energy and other nutrients in diets for Characid fish. Pijuayo (*Bactris gasipaes*), plátano (*Musa paradisiaca*), and yucca (*Manihot sculenta*), which are all widespread in the Amazon region, have good potential to supply nutrients and energy in compound diets for Characids based on growth in previous trials (Kohler et al., 2005; Lochmann et al., 2005). However, more response variables must be measured to ensure that overall performance of Characids fed compound diets containing these products is equal to or better than diets with traditional ingredients. We conducted two separate feeding trials to determine the effects of a control diet (wheat) versus diets with one of three native Amazonian plant feedstuffs on the performance of juvenile *C. macropomum* (Trial 1) and *P. brachypomus* (Trial 2). Diets were formulated to contain similar amounts of total protein and energy and differed only in the test feedstuff (wheat, pijuayo, platano or yucca, supplied at 30% of the diet) being evaluated as an energy source. Because cooking increases the available energy in starch (Lovell, 1989), we also tested cooked and uncooked versions of each of the native feedstuffs. Weight gain (g), feed conversion ratio (FCR), liver glycogen and dry matter, hematology (hematocrit, hemoglobin, and mean corpuscular hemoglobin concentration), and immune parameters (lysozyme and alternative complement activity) were measured to assess diet effects.

MATERIAL AND METHODS

2.1. Experimental diets

Two separate feeding trials were conducted in a recirculating system using similar conditions. Gamitana (*Colossoma macropomum*) was used in Trial 1, and paco (*Piaractus brachypomus*) was used in Trial 2. Diet formulations were identical in both experiments. The formula of the basal diet and the analyzed proximate composition of the seven test ingredients are shown in Table 1. The diets supplemented with uncooked or cooked pijuayo, plantain, and yucca were formulated to contain around 30% crude protein on a dry basis. The control diet containing wheat bran was higher in protein (33.5%) due to the higher crude protein content of wheat bran (16.1%). Soybean meal and menhaden fish meal were the main protein sources, and all diets met the estimated essential amino acid requirements of this species (Van der Meer and Verdegem, 1996). The test ingredients were evaluated primarily as energy sources relative to wheat bran. All diets contained soybean oil as the primary lipid source, with traces of oil from rice bran and fish meal. The diets supplemented with wheat bran, uncooked, or cooked pijuayo contained 11-12% total lipid on a dry basis, and the diets with uncooked or cooked plantain and yucca contained about 9.5% total lipid due to their low lipid content in the test ingredients. The ingredients in uncooked or cooked plantain and yucca contained 90-92% carbohydrate, over 30% higher than that of wheat bran and 15% higher than those of uncooked or cooked pijuayo. Wheat bran was made from soft wheat dry-milled without heat to obtain the bran (Caldwell milling Co., AR, USA). Raw plantain and yucca were purchased locally, then cut into thin slices after peeling. Uncooked plantain and yucca were processed by directly drying in an oven at 60 °C. Cooked plantain and yucca were obtained by drying after the slices were boiled in water by using a pressure cooker. The pijuayo was purchased in Peru and processed similarly to yucca and plantain before shipment to UAPB. All ingredients were finely ground (1-2 mm) in a Wiley mill prior to inclusion in diets. Diet ingredients were fully mixed in a V-mixer and 600 ml of distilled water was added per kilogram

of dry diet in a Berkel mixer to achieve a doughy consistency. A meat grinder fitted with a 3-mm die was used to produce stable pellets, which were fan-dried and stored at -18°C until needed. Ingredients and diets were analyzed at UAPB using the Kjeldahl method for crude protein, the Folch extraction method for total lipid (Folch et al., 1957), and the Ankom method for crude fiber.

2.2. Culture system and experimental design

The gamitana fingerlings for trial 1 were obtained from a producer in Iquitos, Peru, and shipped to the Aquaculture Research Center at UAPB, Arkansas, USA. The fish were fed a commercial Silvercup™ largemouth bass feed for four weeks prior to stocking, when they had no clinical signs of diseases. Eight uniform fish were randomly selected and stocked into each of four 110-L aquaria, which in turn were assigned to each treatment. Individual initial weight of fish was 22.5 ± 0.03 g (mean \pm SEM). Aquaria were configured in a recirculating system using dechlorinated municipal water with hardness adjusted to of 80-120 mg L⁻¹ with calcium chloride. Water quality was monitored weekly and maintained by a biofilter, continuous aeration, and a flow rate of 1 L min⁻¹ per aquaria. Water temperature was maintained at $28 \pm 1^{\circ}\text{C}$ during the feeding trial. Fish were fed to apparent satiation, which was approximately 4% of their body weight daily for the first six weeks, followed by 3% of body weight after six weeks. Daily rations were divided into two equal feedings (8:00 and 16:00 h). Fish from each tank were weighed collectively every two weeks after stocking to monitor growth and adjust feed rations. After six weeks of feeding, three fish per tank were sampled for glycogen analysis based on average individual weight of fish in each tank. Final average individual weight gain and feed conversion ratio (dry feed weight/weight gain) were calculated at twelve weeks. Two fish per tank were euthanized with an overdose of MS-222, and their livers were removed and frozen at -70°C until analyzed for glycogen concentration. Remaining fish were returned to their tanks and maintained on their respective diets for another two weeks prior to health assays (alternative complement activity and hematology) to minimize the influence of handling stress on the results. An additional assay (lysozyme activity) was performed in trial 2 only. In each trial, three fish per tank were euthanized and bled for health assays.

Paco fingerlings for trial 2 were obtained from a producer in Florida, USA, and acclimated to a recirculating system with 144-L tanks. The tanks operated as a recirculation system with a 565-L sump and large bubble-wash bead filter. Each tank was supplied with an air stone to maintain supplemental aeration. Fifteen fish with individual initial weight of 2.56 ± 0.01 g (mean \pm SEM) were stocked into each of 3 tanks per diet. Other experimental conditions were the same as in trial 1, except where noted.

2.3. Liver glycogen analysis

At six and twelve weeks, livers were removed from two fish per tank, pooled and homogenized, then frozen until analysis. One hundred milligrams of each pooled sample was weighed and analyzed using the method of Good et al. (1933). Tissue samples were digested in hot concentrated (30%) potassium hydroxide solution, followed by precipitation of the glycogen with 95% ethanol, hydrolysis of the glycogen with 0.6 N hydrochloric acid, and determination of the glucose in the hydrolysate as reducing sugar. A blue color was formed by the reaction of cuprous oxide with arsenomolybdic acid after boiling a solution of copper sulfate with glucose. Absorption of the solution was measured a Kinetic microplate reader (Molecular Devices, Sunnyvale, CA) at 505 nm. Glycogen concentration in a liver sample was calculated by multiplying glucose concentration with a conversion factor of 0.93.

2.4. Blood sample collection and analysis

After 12 weeks in each trial, fish were not fed for 24 h then anesthetized with tricaine methanesulfonate (MS-222). Blood from three individual fish each tank was collected using heparinized 3-ml syringe with 18-G needle, then transferred into a 1.5-ml microcentrifuge tube. Eight μl of fresh blood in duplicate from each fish was sampled for the analysis of hemoglobin content (hemoglobin cyanide method). Mean corpuscular hemoglobin concentration (MCHC) was calculated on an individual basis by the formula: $\text{MCHC} = \text{hemoglobin}$

concentration/hematocrit fraction. After centrifuging each blood sample collected in a heparinized micro-hematocrit tube, hematocrit value was measured in duplicate for each fish, then 25 μ l of fish serum was collected for a hemolytic assay of alternative complement activity.

2.5. Hemolytic assay (alternative complement pathway)

The hemolytic activity driven by the alternative complement pathway was measured using the washed rabbit red blood cells as target cells in the presence of ethyleneglycoltetraacetic acid (EGTA) and Mg^{2+} , as described by Tort et al. (1996). The ACH 50 was determined by measuring the optical density of the hemolytic supernatant after adjustment of the optical density of the diluted fish serum at 414 nm by a Kinetic microplate reader (Molecular Devices, Sunnyvale, CA), as described by Chen et al. (2003).

2.6. Lysozyme analysis (Trial 2 only)

Fifty μ l of fish plasma was added into each well in a 96-well plate. One hundred and fifty μ l of suspended *Micrococcus lysodeikticus* (0.4mg ml⁻¹ in phosphate buffer) was mixed with the fish plasma in each well, and the reduction in the absorbance reading at 450 nm was taken every 10 sec for 5 min using the basic kinetic protocol of the microplate reader with SoftMax Pro 4.3 (Molecular Devices, Sunnyvale, CA). One unit of lysozyme activity was defined as a reduction in absorbance of 0.001 / min (1milli OD min⁻¹).

2.7. Statistical analysis

Each of the seven dietary treatments was randomly assigned to four (Trial 1) or three (Trial 2) aquaria in a completely randomized design. All the data were analyzed by analysis of variance (ANOVA) in a StatView program (SAS Institute, Inc., Cary, NC). When significant differences among treatment means were found ($P \leq 0.10$), treatment means were compared using Fisher's least significant difference test.

RESULTS AND DISCUSSION

3.1. Growth, feed conversion and liver composition

Trial 1. There were no differences in weight gain or feed conversion efficiency of gamitana fed diets with different feedstuffs (Table 2), indicating that all of the test ingredients were suitable energy sources relative to wheat bran. Hepatosomatic index of fish fed the diet with uncooked plantain was higher than that of fish fed all other diets (Table 2). At 12 weeks, fish fed the diet with cooked yucca had lower liver glycogen than fish fed other diets except for those fed diets with uncooked yucca or wheat bran. Liver dry matter was lowest in fish fed diets with wheat bran or cooked yucca. Survival was 100% in all aquaria.

Trial 2. Weight gain and FCR also did not differ by diet for paco (Table 3). Fish fed the diet with cooked yucca had the highest HSI (Table 3), while fish fed diets with wheat bran or uncooked plantain had the lowest. Liver glycogen was higher in fish fed diets with cooked yucca than in all other fish except those fed diets with cooked plantain (Table 3). Fish fed the diet with wheat bran had lower liver dry matter than fish fed all other diets (Table 3.) Fish fed the diets with cooked or uncooked pijuayo had higher liver dry matter than fish fed cooked or uncooked yucca (Table 3). Three fish disappeared from one tank during the study, but these were not diet-related mortalities and survival was 100% in all other tanks.

Heating increases the available energy of starch by 10-15% (Lovell, 1989). However, there was no indication that raw and cooked versions of the pijuayo, plantain, and yucca differed in available energy for *C. macropomum* because weight gain and glycogen accumulation in liver were not higher in fish fed cooked versions of the feedstuffs. In paco, however, the cooked yucca and cooked plantain resulted in more glycogen accumulation in the liver, indicating that cooked versions of those ingredients did provide more available energy. It is difficult to determine how much of the differences in responses of gamitana and paco were due to species differences versus fish size. The gamitana were approximately 10 times larger than the paco initially. Within a

species, small fish generally have a more rapid growth rate and a higher energy requirement than large fish (Webster and Lim, 2002). Small fish tend to have lower glycolytic capacity than larger ones (Garenc et al., 1998), but glycogen accumulation in the liver is also affected by diet, health, and the energy status of the fish (e.g., Craig et al., 1999; Hemre et al., 2000). Paco in this study consumed feed voraciously and it appears that the fish had excess dietary energy for glycogen synthesis after their metabolic needs were met.

3.2. Hematology, complement (ACH50) and lysozyme

Trial 1. After 12 weeks gamitana fed the diet with wheat bran had lower hemoglobin than those fed the other diets (Table 4). There were no differences in hematocrit, mean corpuscular hemoglobin concentration (MCHC), or alternative complement activity (ACH50) among fish fed different diets. Lysozyme activity was not detected, but it is likely that an inappropriate pH was used in the assay. Additional work is needed to optimize the pH for lysozyme detection in *C. macropomum* because this value is species-specific.

Trial 2. After 12 weeks paco fed the diet with wheat bran had lower MCHC than fish fed other diets (Table 5). The MCHC was also lower in fish fed uncooked plantain than those fed other diets except for uncooked pijuayo. There were no differences in hematocrit, hemoglobin, ACH50, or lysozyme activity among treatments (Table 5).

The most obvious difference between the wheat bran diet and the diets with native feedstuffs was the lower available energy content of wheat bran compared to pijuayo, yucca or plantain. This was due to the higher percentage of indigestible fiber (9.9%) in wheat compared to the native feedstuffs (0.2 – 4.5%). Despite the fact that fiber is not an energy source for monogastric animals, it appears to stimulate growth in some Characids. *Piaractus mesopotamicus* grew better on diets with 16% fiber than with diets containing 4-12% fiber (Zanoni, 1996), but most fishes do not benefit from such high levels (NRC, 1993). For instance, least-cost feed formulations for channel catfish stipulate a maximum of 7% indigestible fiber because it reduces total dietary energy and can reduce the availability of energy and nutrients from other diet ingredients (Robinson and Li, 2006). In addition, increased fecal output resulting from a diet high in fiber can reduce water quality (Robinson and Li, 2002). It is possible that some types of indigestible fiber stimulate growth indirectly in Characids, perhaps through a prebiotic effect on the intestinal microflora (Vasquez et al., 2006), but this has not been investigated.

In our study some of the hematological parameters were depressed in fish fed the diet with wheat bran compared to fish fed the other diets. However, indices of immune response (ACH50 and lysozyme) were not affected by diet and survival was high in both trials, indicating that the hematological effects observed were not deleterious to the fish.

CONCLUSIONS

All of the native feedstuffs tested appear to be good sources of available energy for *Colosomma macropomum* and *Piaractus brachypomus* relative to wheat bran (control). The availability of energy from feedstuffs is inversely associated with fiber content, and wheat bran is higher in fiber than all of the other ingredients tested. The extra energy in the native feedstuffs, however, was used for glycogen synthesis rather than whole-body growth because no significant differences in body weight occurred among fish fed different diets. Dietary effects on fish health in this study were mild and inconsistent, indicating that pijuayo, yucca and plantain are also safe energy sources with no obvious anti-nutritional effects.

ANTICIPATED BENEFITS

Use of pijuayo, plantain and yucca as energy sources in growout diets of gamitana and paco may reduce diet costs and increase utilization of locally available ingredients in the Amazon region.

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Table 1. Composition of diets containing uncooked or cooked Amazonian plant feedstuffs (pijuayo, plantain, and yucca) for grow-out of gamitana (*Colossoma macropomum*) and paco (*Piaractus brachypomus*)

Ingredients	Concentration (g kg ⁻¹ dry diet)				
Menhaden fish meal	100				
Soybean meal	400				
Rice bran	120				
Corn meal	40				
Soybean oil	30				
Vitamin mix ¹	5				
Mineral mix ¹	5				
Test ingredients ²	300				
<i>Proximate composition of test ingredients</i>	<i>Protein³ (%)</i>	<i>Lipid³ (%)</i>	<i>Ash³ (%)</i>	<i>Fiber³ (%)</i>	<i>NFE³ (%)</i>
<i>Wheat bran</i>	16.1	6.8	7.1	9.9	60.1
<i>Uncooked pijuayo</i>	7.6	9.0	1.7	4.9	76.8
<i>Cooked pijuayo</i>	6.7	9.5	1.6	4.5	77.7
<i>Uncooked plantain</i>	3.9	1.2	3.5	0.2	91.2
<i>Cooked plantain</i>	4.9	1.2	2.9	0.9	90.1
<i>Uncooked yucca</i>	3.4	0.9	2.3	1.1	92.3
<i>Cooked yucca</i>	4.1	0.5	2.4	1.5	91.5

¹ Same as Fernandes et al. 2004.

² Test ingredients were included at 30% of each diet on a dry basis. Wheat bran was used as the control.

³ Proximate composition data are shown on a dry basis. Nitrogen-free extract (NFE) = 100 - (protein + lipid + moisture + ash + fiber).

Table 2. Average individual weight gain, feed conversion ratio (FCR), hepatosomic index (HSI), and liver glycogen and dry matter of gamitana fed diets containing wheat bran, or uncooked or cooked pijuayo, plantain, or yucca for 12 weeks¹

Test ingredient	Weight gain ² (g)	FCR ³	HSI ⁴ (%)	Liver	
				Glycogen ⁵ (%)	Dry matter (%)
Wheat bran	88.0±4.5	1.86±0.09	1.22±0.08 ^a	15.0±3.0 ^{ab}	20.2±0.7 ^a
Uncooked pijuayo	89.7±4.0	1.80±0.08	1.38±0.13 ^a	19.9±5.9 ^{bc}	22.6±0.8 ^b
Cooked pijuayo	93.5±3.2	1.75±0.04	1.31±0.06 ^a	20.6±4.4 ^{bc}	23.5±0.7 ^b
Uncooked plantain	100.6±9.1	1.66±0.10	1.83±0.10 ^b	26.5±0.4 ^c	23.4±0.4 ^b
Cooked plantain	94.3±10.4	1.76±0.15	1.24±0.04 ^a	16.5±2.6 ^b	22.2±0.2 ^b
Uncooked yucca	91.9±7.1	1.77±0.12	1.27±0.08 ^a	15.3±3.7 ^{ab}	22.5±0.1 ^b
Cooked yucca	113.6±9.0	1.56±0.05	1.18±0.05 ^a	6.5±2.7 ^a	20.5±0.6 ^a
	P=0.24	P=0.43	P=0.0003	P=0.03	P=0.003

¹ Values are means ± SEM from four replicate aquaria initially containing 8 fish each before 6 weeks of feeding, then 5 fish each after 6 weeks of feeding. Means in each column with different superscript letter are significantly different ($P \leq 0.10$).

² Initial average individual weight of fish in all treatments was 22.5±0.1g. Weight gain = Final average individual weight (g) – initial average individual weight (g).

³ Feed conversion ratio = dry feed weight (g)/weight gain (g).

⁴ Hepatosomic index = wet liver weight (g)/individual fish weight (g).

⁵ Glycogen in fish liver was shown on a dry basis. Values are means ± SEM of four replicate pooled samples per treatment. Pooled samples consisted of two individual livers each, analyzed in duplicate.

Table 3. Average individual weight gain, feed conversion ratio (FCR), hepatosomic index (HSI), and liver glycogen and dry matter of paco fed diets containing wheat bran, or uncooked or cooked pijuayo, plantain, or yucca for 12 weeks¹

Test ingredient	Weight gain ² (g)	FCR ³	HSI ⁴ (%)	Liver	
				Glycogen ⁵ (%)	Dry matter (%)
Wheat bran	88.5±8.0	1.90±0.06	1.88±0.08 ^d	23.3±1.6 ^d	27.7±0.6 ^c
Uncooked pijuayo	92.6±7.3	1.80±0.07	2.48±0.08 ^b	31.2±1.3 ^b	29.9±0.2 ^a
Cooked pijuayo	95.0±7.3	1.82±0.15	2.32±0.11 ^b	28.3±1.3 ^{bc}	30.0±0.4 ^a
Uncooked plantain	91.1±8.0	1.73±0.09	1.93±0.07 ^{cd}	27.6±1.2 ^c	29.3±0.3 ^{ab}
Cooked plantain	98.9±8.5	1.74±0.08	2.35±0.06 ^b	33.0±1.2 ^{ab}	29.3±0.2 ^{ab}
Uncooked yucca	110.7±7.2	1.66±0.03	2.11±0.10 ^c	29.7±1.2 ^{bc}	28.6±0.4 ^b
Cooked yucca	106.4±1.4	1.66±0.04	2.70±0.06 ^a	34.6±1.4 ^a	28.7±0.3 ^b
	P=0.31	P=0.40	P<0.0001	P<0.0001	P=0.0003

¹ Values are means ± SEM from three replicate aquaria containing 15 fish each. Means in each column with different superscript letters are significantly different (P≤0.10).

² Initial average individual weight of fish in all treatments was 2.55±0.0g. Weight gain = final average individual weight (g) – initial average individual weight (g).

³ Feed conversion ratio = dry feed weight (g)/ weight gain (g).

⁴ Hepatosomic index = wet liver weight (g)/individual fish weight (g).

⁵ Glycogen is shown on a dry basis. Values are means ± SEM of three tanks per treatment, three fish per tank. Each liver sample was analyzed in duplicate.

Table 4. Hematocrit (Hk), hemoglobin concentration (Hb), mean corpuscular hemoglobin concentration (MCHC), and alternative complement activity (ACH50) of gamitana fed diets containing wheat bran, uncooked or cooked pijuayo, plantain, or yucca for 12 weeks¹.

Test ingredient	Hk ² (%)	Hb ² (g dl ⁻¹)	MCHC ³ (g dl ⁻¹)	ACH50 ⁴ (units 25 µl ⁻¹)
Wheat bran	33.2±1.3	7.3±0.3 ^b	22.1±0.6	23.2±2.2
Uncooked pijuayo	37.1±1.1	8.6±0.3 ^a	23.2±0.3	21.9±1.7
Cooked pijuayo	35.0±0.8	8.2±0.3 ^a	23.4±0.5	21.6±2.3
Uncooked plantain	35.5±1.3	8.3±0.4 ^a	23.3±0.5	21.8±2.3
Cooked plantain	35.9±1.2	8.1±0.1 ^a	22.9±0.6	19.2±1.5
Uncooked yucca	34.2±1.3	8.1±0.3 ^a	23.6±0.5	20.8±2.0
Cooked yucca	35.3±1.1	8.0±0.3 ^a	22.6±0.6	24.1±2.2
	P=0.36	P=0.064	P=0.45	P=0.70

¹ Values are means ± SEM of four replicates per treatment. Three individual fish were sampled per replicate. Means in each column with different superscript letters are significantly different (P≤0.10).

² Hematocrit value and hemoglobin content from each fish were analyzed in duplicate. Hematocrit = Number of red blood cells as a fraction of whole blood.

³ MCHC = Hemoglobin content (g dl⁻¹) / hematocrit.

⁴ Twelve fish from each treatment were analyzed for alternative complement activity.

Table 5. Hematocrit (Hk), hemoglobin concentration (Hb), mean corpuscular hemoglobin concentration (MCHC), serum lysozyme, and alternative complement activity (ACH50) of paco fed diets containing wheat bran, or uncooked or cooked pijuayo, plantain, or yucca for 12 weeks¹

Test ingredient	Hk ² (%)	Hb ² (g/dl)	MCHC ³ (g/dl)	Lysozyme ⁴ (units/50µl)	ACH50 ⁴ (units/25µl)
Wheat bran	39.3±0.9	8.2±0.2	20.8±0.5 ^c	31.6±1.7	37.4±2.9
Uncooked pijuayo	40.5±1.0	9.1±0.2	22.5±0.4 ^{ab}	30.7±1.1	38.4±3.0
Cooked pijuayo	39.2±1.3	9.0±0.3	22.9±0.4 ^a	31.7±1.2	37.8±2.4
Uncooked plantain	41.0±0.8	8.9±0.2	21.7±0.5 ^b	33.8±1.5	36.7±2.6
Cooked plantain	38.2±0.9	8.8±0.3	23.1±0.4 ^a	33.2±1.5	31.9±3.0
Uncooked yucca	38.9±0.8	9.0±0.2	23.0±0.3 ^a	31.5±1.6	38.7±2.7
Cooked yucca	40.0±1.1	9.1±0.3	22.6±0.3 ^a	33.1±1.2	39.1±3.3
	P=0.44	P=0.13	P=0.0003	P=0.69	P=0.63

¹ Values are means ± SEM of three replicates per treatment. Four individual fish were sampled per replicate. Means in each column with different superscript letters are significantly different (P≤0.10).

² Hematocrit value and hemoglobin content from each fish were analyzed in duplicate.

³ MCHC = Hemoglobin content (g/dl)/ hematocrit.

⁴ Twelve fish each treatment were analyzed for the serum lysozyme and alternative complement activity. Lysozyme was analyzed using 50 µl of serum, in duplicate for each fish, and alternative complement was analyzed using 25 µl of serum each fish.

REPRODUCTION OF PACU (*PIARACTUS MESOPOTAMICUS*) AND SURUBIM (*PSEUDOPLATYSTOMA TIGRINUM*) AND A NEW PARADIGM IN NUTRITION OF TROPICAL FISHES

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ABSTRACT

Our aim was to assist students involved in long term training towards the completion of their degrees under the mentorship of CRSP researchers. The task at hand was successfully accomplished when on December 7, 2007, Ms. Yongfang Zhang defended her dissertation entitled "Amino Acid Metabolism and Requirement in Teleost Fish during their Early Life Stages and Implications in Fish Formulated Diets". A short summary of her dissertation work is given below (studies on Nicaraguan cichlid). Furthermore, we completed experiments with pacu juveniles in Brazil utilizing a new imbalanced complimentary diet feeding strategy. The response of free amino acids in the body was examined and used to elucidate the mechanism governing the depression/enhancement of individual amino acids levels in response to the presence or deficiency of indispensable amino acids in the diet. Studies on silver arowana addressed the transition from endogenous yolk sac feeding to external feeding, feed acceptance and characterization of lipid and fatty acid profiles in the fish body. Osteoglossid fish, the oldest lineage of teleosts, appear to have selective utilization of essential fatty acids accumulated in yolk reserves and these findings stand to make a significant contribution toward the formulation of a starter diet for this species.

INTRODUCTION

One of the missions of aquaculture is to prevent overfishing of natural populations of ornamental and/or endangered fish as well as to promote the utilization and conservation of wild stocks in the Amazon rainforest. Such objectives can be only achieved if sufficient economic incentives are present. Controlled culture of arowana (*Osteoglossum bicirrhosum*) may considerably limit the illegal international trade of this osteoglossid species (Moreau and Coomes, 2006). Commercial fisheries are known to also over-exploit Amazonian catfishes (*Pseudoplatystoma* sp.) (Allan et al. 2005), which are highly valued in the aquarium industry. At present, ornamental fish imports have increased in the U.S. by 50% since 2000, and were worth \$46.1 million in 2005 (Aquaculture Outlook, 2006). The educated and informed public in developed countries is likely to be receptive

to the notion of domestic production of aquarium fishes and the preservation of natural stocks in the Amazon and other pristine areas of South America. Therefore, the production of Amazonian fish in controlled intensive production facilities is expected to be very appealing to the public. At present, wholesalers in the USA offer juvenile arowana at a price of \$20-60 per fish. Export of silver arowana from the Amazon reached 560,000 USD in 2005 (Moreau and Coomes, 2006).

The commercial larval rearing of tropical fish species presents a great challenge to farmers because of the high mortality that occurs during the larval phase, especially due to the feeding habits of the catfishes which include cannibalism. Generally, South American catfish producers use live *Artemia nauplii* for the initial feeding of larvae, followed by feed training (habituation), when the fish are adapted to formulated diets. We have only just begun to generate information on the nutritional requirements of these species in our laboratory (Arslan et al. 2008; Dabrowski et al. 2008), and subsequently survival rates during this period have significantly improved.

Feeding experiments with Nicaraguan cichlid

Materials and Methods: In these experiments we used a surrogate species for surubim. This fish, the Lake Nicaragua cichlid, midas (*Amphilophus citrinellum*), is of growing importance in Central America aquaculture. The purpose of this dissertation were two fold, (1) to study the utilization of dietary amino acids in teleost fish during their early life stages (larvae and juvenile), and (2) to investigate the effect of indispensable amino acid (IDAA) imbalanced diets on young teleosts in terms of their body weight gain, feed intake, feed conversion rate and the concentration of whole body (or muscle) free amino acids. In this set of experiments, we examined the effect of IDAA-imbalanced diets on juvenile teleosts, and tested a IDAA imbalance/complimentary feeding strategy that may eliminate the adverse effects of IDAA deficient diets on young fish. In experiment 1, two IDAA imbalanced diets, (-) the Lys diet (where Lys, His, Ile, Phe and Trp were missing from the diet) and the (-)Arg diet (where Arg, Thr, Val, Leu and Met were missing), and two IDAA balanced diets, a casein-gelatin-based diet (protein control) and a FAA-based diet (FAA control), were tested in juvenile midas.

Results: We observed that fish initially responded by decreasing feed intake, but two weeks into the experiment, fish fed the (-)Arg or (-)Lys diets had a significantly increased intake of amino acid imbalanced diets. Fish fed the FAA diet or IDAA imbalanced diet showed a decreasing trend in their whole body IDAA concentrations, which differed from the fish fed with the protein diet. In experiment 2, three diets, a FAA-based diet (control diet), the (-)Lys and (-)Arg diets, were used. Juvenile midas were provided with FAA imbalanced diets using several different feeding strategies. The principle was that within a 2-day frame, all fish get the same amount of dietary IDAA throughout the 32-day experiment period. After 32 days, fish in all feeding treatments increased their body weight significantly, but the final weights linearly decreased with lower frequency of complimentary diet provision.

Fish in the group fed with -Lys-Arg -Lys-Arg (interchangeably) exhibited well balanced whole body IDAA and DAA profiles (after the last meal of the day; Fig. 1) and higher final body weight gain compared to other IDAA imbalanced diet fed groups. This implies that IDAA imbalanced diets along with an appropriate feeding strategy in terms of a IDAA deficient/complete provision schedule, and feeding intervals, can sustain positive growth in juvenile midas.

Pacu reproduction and nutrition

Materials and Methods: We worked to complete a series of experiments on the reproduction and nutrition of tropical fish in Columbus (utilizing a recirculation system) and in Jaboticabal, CAUNESP, Brazil, with an open system. Achieving improvements in economic and energy savings in operations of aquaculture utilizing recirculation systems (ARS) must include the consideration of sources of heat provision, waste/nutrient conversion to bacterial biomass, and the culture of fish species of high value as food or to the aquarium trade. These objectives will allow substantial cost savings in energy and increase the production capacity of the current ARSs operating in the USA.

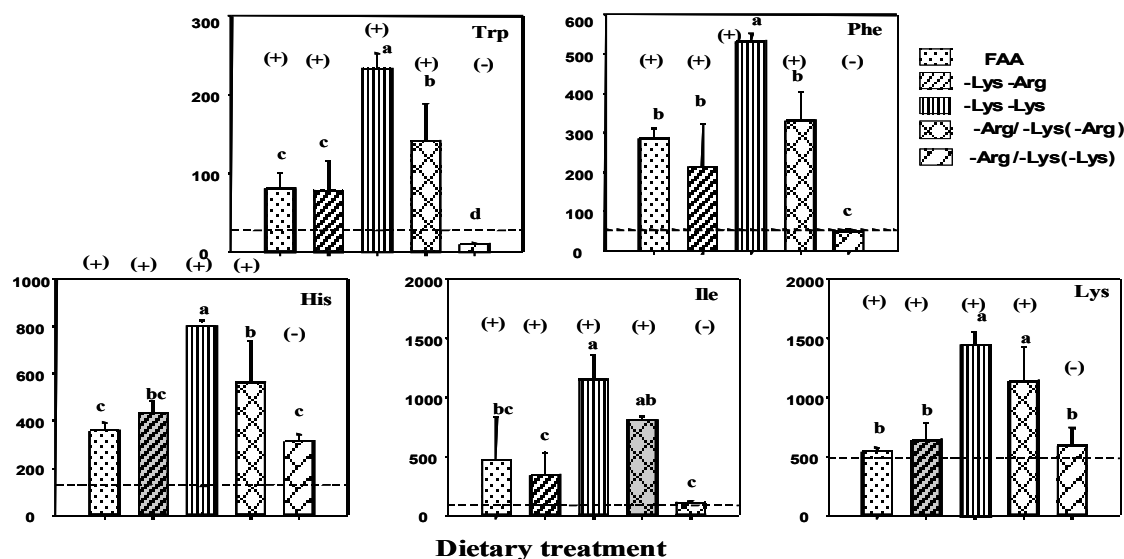


Figure 1. Whole body IDAA concentrations (umol/kg) in midas three hours after the last meal of the day. The dashed line indicates the concentrations of free amino acid in fish fasted for 48-h. Data are expressed as mean \pm S.D, n=3. Different letters above bars indicate that there are significant differences among the dietary treatments (p<0.05). (“+” or “-” above the bars: presence/absence of specific IDAA).

Results: At present, we have experienced considerable variation and limited scope in regulating seasonal changes of water temperatures, pH, and light regime in our ARS in Columbus (Fig. 2) which results in partial unpredictability of the maturation cycle and controlled induction of gonad development in tropical fish. Therefore, following our experiences in early winter 2007 (January-March) when hormonal induction of ovulation failed we introduced a water cooling and low light regime in July-August 2007 (marked by arrows) that corresponded to the winter conditions in Central Brazil (Sao Paulo State). We monitored fish growth during this period until January 2008 (Fig. 2). In addition, we introduced a new ultrasound technique to monitor gonad growth *in vivo*. The first set of tests was carried out in July 2007, and some fish were sacrificed, deep-frozen and cross sections were made to validate readings (Fig. 3).

The first series of experiments was carried out in CAUNESP Jaboticabal with pacu, *Piaractus mesopotamicus*, a native species extensively cultured in Brazil because of its fast growth and high consumer acceptance. The present study aimed to compare pre-feeding and postprandial body free amino acid (FAA) levels in fish fed protein-based (CG), free amino acid (FAA)-based, indispensable amino acid (IDAA)-balanced and IDAA-imbalanced diets and to understand how disproportional amounts of IDAA in pacu diets can affect free amino acid levels in fish tissues. Pacu juveniles (mean weight: 97.6 ± 10.0 mg) were stocked into 16 tanks (100L capacity). Four isonitrogenous and isolipidic diets were used in this experiment, each one assigned to four tanks. The diets were: (a) casein-gelatin-based diet (CG, protein control), (b) FAA-based diet (with all indispensable amino acids), (c) (-)Lys diet (deficient in Lys, His, Ile, Phe and Trp and (d) (-)Arg diet (deficient in Arg, Thr, Val, Leu and Met). Amino acids were supplied in the form of L-free amino acids in FAA, (-)Lys and (-)Arg diets. Juveniles were fasted for 48 hours and then fed *ad libitum* with different diets. Postprandial sampling took place 30 min after a meal. Mortality was monitored and moribund fish were removed to avoid cannibalism. Growth performance was assessed and free amino acids were quantified by reverse-phase high performance liquid chromatography (RP-HPLC).

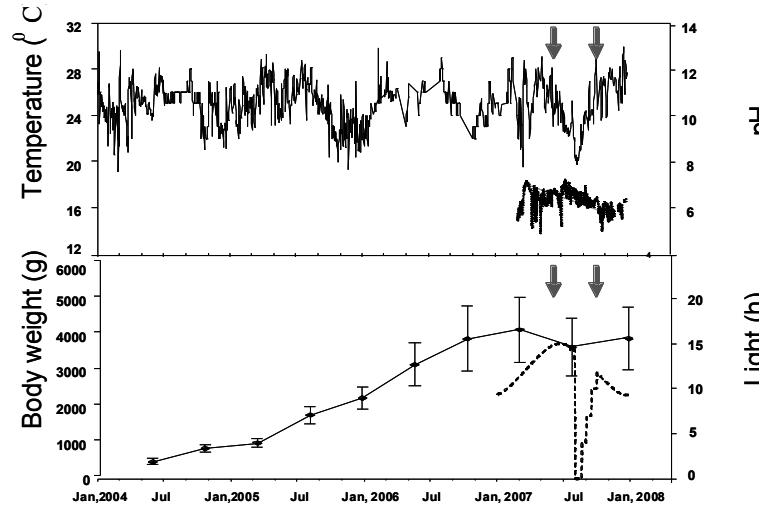


Figure 2. Growth of pacu in ARS (Kottman Hall) with temperature, pH, and light regime fluctuations. Arrows indicate duration of water temperature cooling and short day light.

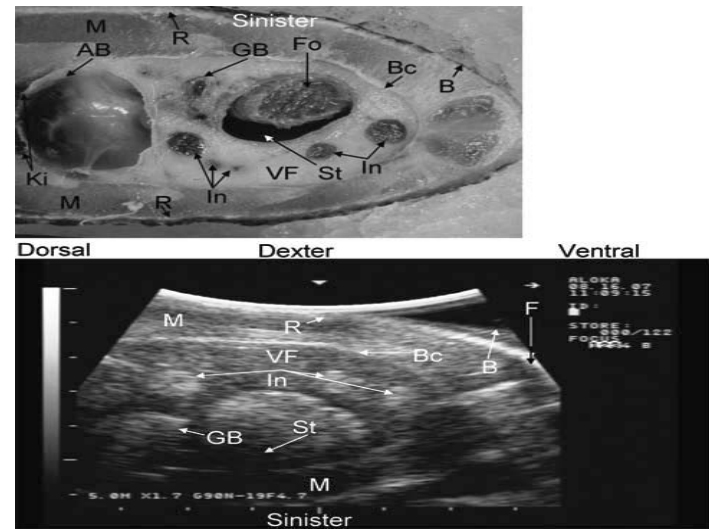


Figure 3. An immature necropsied pacu was first scanned then assessed via cross sections to gain knowledge on their appearance before scanning live pacu. An Aloka (Aloka Co., LTD) SSD-500V ultrasound with a Medi-capture USB100 video capture system with an attached homeland security camera, and 3.5 MHz convex array probe was used to scan the fish. AB = Air bladder; Bc = body cavity wall; F = fin; Fo = food; GB = gall bladder; In = intestine; Ki = kidney; Li = liver; M = muscle; R = ribs; St = stomach; VF = visceral fat.

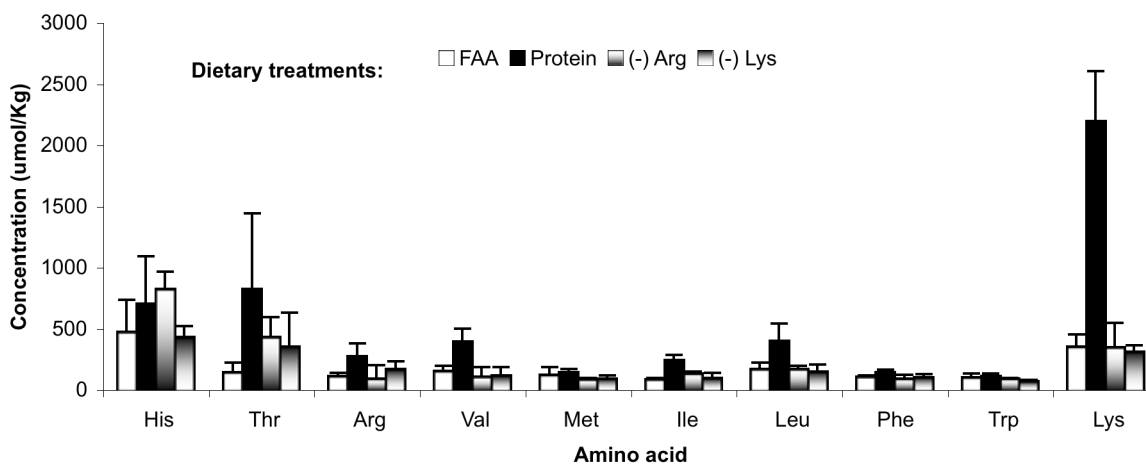


Figure 4. Concentrations of indispensable amino acids in the whole body of pacu juveniles following 60 days of feeding (sampling 3h after a meal).

In preliminary samples, postprandial levels of free amino acids (FAA) in body tissues showed no difference ($P>0.05$), however, the analysis will ultimately also include concentrations of free amino acids after the termination of feeding (Fig. 4).

Experiments with a new species, silver arowana

Materials and methods: We concentrated on another species from the Amazon region, silver arowana (*Osteoglossum bicirrhosum*). Silver arowana was obtained through ornamental trade outlets and according to the dealer was originally from Colombia. Several fish were fixed for histological analyses when intense absorption of the yolk was taking place. We examined fish ($n=12$) of 50-65 mm total length with yolksacs extended up to 11.8 mm, as well as completely absorbed.

Results: The present results confirm that the yolk of this species is divided into two parts: an external part visible from outside, and an internal part in the abdominal cavity. The internal compartment of the yolk is present around the liver, between the liver and the notochord, stomach, and gas bladder.

Light microscopy allowed us to conclude that the internal part of the yolk is an extension of the external yolk (Fig. 5). In some transverse sections it was found that the liver tissue is located between these two parts along with a structure which could be regarded as a *ysl*. The *ysl* can be distinguished as an integral part of the external yolk, but on its upper apex it borders the lower part of the internal compartment of the yolk. There are differences in the structure of the external and internal part of the yolk, including the appearance of blood vessels which collect blood enriched with nutrients and provide these to the liver. The internal part of the yolk is poorly vascularized and only capillary vessels were found on its surface. Some differences in the rate of the utilization of the yolk were expected on the basis of morphological studies. It was observed that while the internal part of the yolk has a coalescent appearance the external compartment seems to be a more heterogeneous structure.

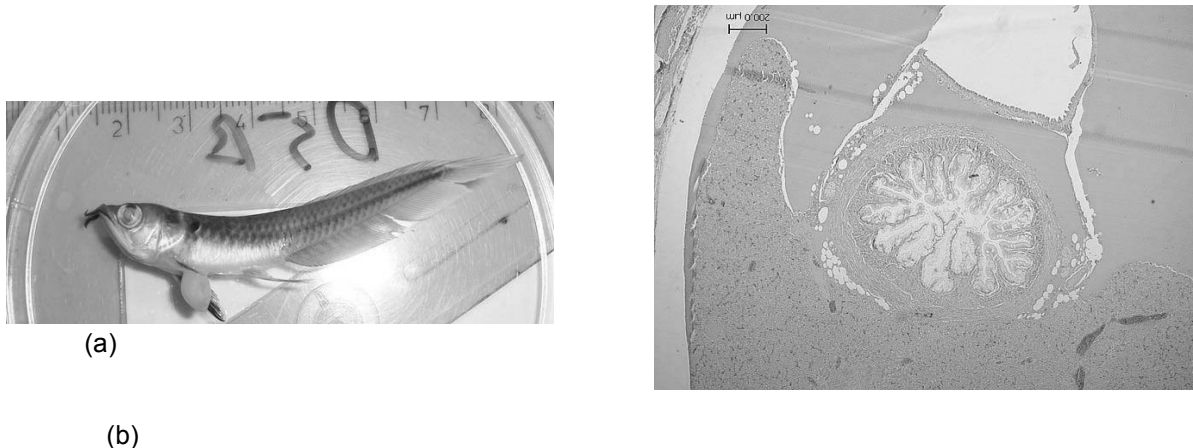


Figure 5. (a) Larva of silver arowana close to the conclusion of the endogenous feeding with a distinct external yolksac. (b) The histological section shows that at this moment the alimentary tract is well developed; sb – swim bladder, sto – stomach; eso – esophagus, in-y – internal yolk; stained with H+E, light microscopy.

However, at the conclusion of endogenous feeding (when most of the visible yolksac was absorbed) no internal part of the yolk was found when the remnants of the external part were still present. Questions remain about the divisions, ultrastructure, and functions of the *ysl* in silver arowana, and also about possible differences in the chemical composition of the two parts of the yolk.

There is sound evidence indicating that maternal lipids accumulated prior to vitellogenesis in muscle/liver are deposited in eggs and consequently in the yolksac of developing fish larvae. This information encouraged us to determine the lipid and fatty acid composition in the yolksac and body of arowana larvae and compare these fatty acid profiles with “historical” samples of adult arowana collected in Peruvian (Iquitos and Pucallpa) fish markets in the Amazon region (CRSP project 1998-2004). The lipids were extracted from the external yolksac and the body and then separated into neutral and phospholipid fractions. Fatty acid profiles were determined in separate fractions. Lipids extracted from muscle samples of adult arowana and another osteoglossid fish, paiche (*Arapaima gigas*), were analyzed via similar procedures. Significant differences in fatty acid profiles in yolk and larval body lipids were found that were unrelated to profiles from muscle of wild adult fish (Amazon). The observed higher levels of arachidonic acid (ARA) compared to docosahexaenoic acid (DHA) in the yolksac PL were somewhat surprising. A high level of linoleic acid in the NL fraction of the yolk and larval body lipids was noticed. These results seem to suggest that at this point of yolk lipid absorption (50%), no elongation or desaturation of C18 fatty acids is taking place during endogenous feeding.

Tropical gar- differentiation of the digestive tract

Materials and methods: We have obtained preserved specimens of tropical gar (*Atractosteus tropicus*) embryos from Department of Biology, Aquaculture Laboratory, University of Tabasco, Mexico (Dr. Wilfrido Contreras and Arlette Hernandez-Franyttui).

Results: In the embryos and larvae of the tropical gar the yolksac is surrounded by vitelline circulation which consists of many capillaries and large blood collecting vessels (preliminary data was presented by Jaroszewska and Dabrowski in 2006 in Villahermoze, Mexico, during “Lepisosteid Symposium”). It can be presumed that in the advanced larvae of the gar the absorption of the mobilized yolk nutrients are entirely released into the vitelline blood circulation system and then transported to the fish’s growing tissue. The degradation and transport of yolk-

derived material in the developing and energy-depending embryo has been described in selachian (chondrichtyan) fish, in which the yolk sac, from the onset of embryogenesis, is in contact with the primordial endodermic gut epithelium. There is no contact in teleosts fish, between the presumptive gut and yolk reserves during the whole embryonic and early larval development (see above in arowana) while, for example, in amphibia, the epithelial cells of the embryo that border the yolk contain yolk particles in their cytoplasm.

ANTICIPATED BENEFITS

We have demonstrated successful reproduction of S. American catfish but were unable to induce reproduction in pacu. The latter species may require more elaborate environmental regime manipulation, involving light, temperature, pH, perhaps also simulation of the migratory behavior (forced swimming). We have successfully raised larvae and juveniles of *Pseudoplatystoma* and *Osteoglossum* and have begun addressing questions related to the nutritional requirements of these species. We used a model cichlid species and juvenile pacu to validate a new feeding strategy based on the use of imbalanced amino acid diets. All the results are applicable to practical aquaculture in the tropics, particularly South America, as well as to the feed manufacturing industry, and could be used to make formulated diets more affordable.

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Financial support from CNPq (Brazil) to M.C. Portella is acknowledged.

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

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

Final Report

Published as Submitted by Contributing Authors

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ABSTRACT

Bivalve culture is an important and growing segment of the aquaculture industry in Mexico and globally. Shellfish sanitation issues were identified in previous CRSP-sponsored research as an impediment to continued growth, export potential, human health and consumer perception of the product. Water sampling for coliform bacteria was conducted at two major oyster cultivation sites in Mexico to identify specific areas within oyster culture sites that would be adequate to assure safe production of oysters and other bivalves. Boca Camichin is an estuarine area located in Nayarit, Mexico where there is an active oyster culture industry using the native species "Pleasure Oyster", *Crassostrea corteziensis*. Bahia Santa Maria (BSM-Santa Maria Bay) is an estuary/coastal lagoon system in Sinaloa, Mexico, where the Japanese oyster, *C. gigas* is cultured. Water quality standards for shellfish growing waters in Mexico are address in the Official Mexican Regulation NOM031-SSA1-1993 which establishes the following for approved shellfish growing waters:

For total coliform bacteria, the median or geometric average should not exceed 70 NMP/100 ml; no more than 10% of the samples should exceed 230 NMP/100 ml with a serial dilution of 5 tubes or 330 NMP/ 100 ml with a serial dilution of 3 tubes.

For fecal coliform bacteria: the median or geometric average should not exceed 14 NMP/100 ml; no more than 10% of the samples should exceed 43 NMP/100 ml with a serial dilution of 5 tubes or 49 NMP/ 100 ml with a serial dilution of 3 tubes.

U.S. standards are similar although coliform levels used for standards are slightly lower (FDA 2003; 2007).

Water sampling was conducted 5 times between February 2006 and January 2007 at Boca Camichin at 30 sampling stations, and 5 times between March 2006 and January 2007 at Bahia Santa Maria at 37 sampling stations. Laboratory analysis of coliform bacteria was conducted at

the Autonomous University of Sinaloa, Marine Science Department, Mazatlan, Mexico, using a 3 tube, serial dilution method.

For samples taken from Boca Camichin, the highest concentration of total coliform bacteria was found in July, September and December (median > 110 NMP/100ml) and the lowest concentrations were found in February, 2006 and January 2007 (median ranging between 55 and 93 NMP/100ml). The highest concentration of fecal coliform bacteria was found in September (median = 93 NMP/100 ml; average = 84.62 NMP/100ml) and the lowest concentration was found in February 2007 (median = 10.5 NMP/100 ml; average = 17.6 NMP/100 ml). For all sampling events, levels exceeded the legal standards for approved shellfish growing areas. Based on these results, Boca Camichin would be classified as a restricted shellfish growing area such that oysters may be cultured, but would be required to undergo depuration before sales. Given that Boca Camichin is a major oyster producing area where social sector (cooperative) farmers own the farms and from which product is widely distributed, these results have serious implication both for regional public health and for the economic well-being of the farmers. Inadequate human waste disposal in the community that surrounds Boca Camichin is most likely the source of contamination. Future CRSP-sponsored research will focus on finding cleaner areas near Boca Camichin where oysters can be relayed and depurated until steps can be taken to address community sanitation issues that impact shellfish sanitation. Public outreach begun as part of the CRSP efforts will continue. In the case of Bahia Santa Maria where shellfish growing waters met standards for approved growing grounds, oyster culture trials can now move forward, as well as on-going water quality monitoring.

INTRODUCTION

This work was initiated in early 2006, ending in September 2007. The primary focus of this work was to conduct water quality monitoring in two major oyster production areas in order to characterize shellfish growing grounds according to the established Mexican bacteriological standards use for classification of shellfish growing waters. Additionally, it was important to not only disseminate results, but to develop action agendas to address problems and take advantage of opportunities presented in coastal areas of Mexico. The work also had a capacity building component for shellfish farmers and Latin American students. The CRSP funded investigation "Outreach and Planning for Implementation of Bivalve Growing Areas Classification and Related Sanitation Action Items (12AHH2) was conducted simultaneously and encompassed much of the public outreach activities to convey the findings of this research and develop an action agenda to address key issues.

Aquaculture diversification is important for the Mexican aquaculture industry in order to expand and to benefit an increased number of stakeholders. Shrimp culture is by far the most important sector of aquaculture in Mexico, but government diversification goals target tilapia and mollusk production. Mexico has dozens of species that are cultured and fished, with many more being good candidates to develop for culture. Currently two species of oysters, the "Pleasure Oyster", *Crassostrea corteziensis*, and the Japanese Oyster, *C. gigas* are the predominant species of bivalves cultured on the Pacific Mexico Coast. *C. corteziensis* is primarily cultured in Nayarit where wild spat collection is feasible. *C. gigas* is cultured mainly in the more northern States of Sinaloa and Sonora and relies heavily on oyster seed imported from the U.S. Boca Camichin, an estuarine area in Nayarit, is home to many small, family and cooperative owned *C. corteziensis* farms which are consumed locally and regionally. Bahia Santa Maria (BSM), an extensive system of coastal lagoons and estuaries, is the site of *C. gigas* farms with more being planned. In particular, the team working on this project has concurrently been working with women's and fishers groups in BSM to begin pilot oyster culture projects for both species.

Past-CRSP sponsored work conducted during research to develop three case studies designed to elucidate the relationships between human health, environmental conditions and aquaculture included these investigations:

Food Safety and Handling: Increasing Local Consumption of Aquaculture Products and Improving Quality (11DPPR1)

Analysis of Critical Points in Aquaculture Production Affecting Participation and Level of Benefits to Women, Youth, and Disadvantaged Stakeholders (11AHHR3)

Connectivity of Water Resource Status, Environmental Quality, Aquaculture, and Human Health (11AHHR2)

This work revealed that sanitation is a problem for nearly all aquaculture production and post-harvest activities occurring on the Pacific Mexico Coast. In particular, serious issues were found with shellfish aquaculture. Additionally, increasing population growth, lack of pollution controls and increasing urbanization of the coast forebode these problems increasing in the future. Bivalve shellfish are among the species which are easiest to culture and the most nutritious, but can also present the most significant risk for consumers because of the danger of shellfish-borne pathogens (e.g. Salmonella, Hepatitis A, E. coli), presence of toxins from red tides, tendency to accumulate heavy metals and vulnerability to post-harvest contamination.

In the United States, shellfish sanitation is regulated by the Food and Drug Administration in conjunction with the Interstate Shellfish Sanitation Committee. The latter is comprised of representatives from each state's responsible agencies and develops and updates standards and procedures which are uniformly adopted and applied throughout the country. Monitoring of shellfish growing waters over many years has led to an information base that allows for classification of shellfish growing areas in the U.S. Mexico has similar bacteriological standards for shellfish sanitation, but is not actively classifying shellfish growing waters except for a few cases. An additional issue is the complexity of having Mexico shellfish growing waters classified as acceptable by the FDA, thus allowing export of shellfish to the U.S., an opportunity many producers would like to take advantage of. At this time, only two areas in Baja California, Mexico are approved for export of shellfish to the U.S.

In Mexico as in the U.S., the presence of *E. coli* in water is used as the primary indicator of contamination that could include a wide range of contaminants such as bacteria and viruses. The level of *E. coli* in a sample is measured as the Most Probable Number (MPN) in a known quantity of liquid media. In Mexico, water quality standards are legally declared in the "Norma Oficial Mexicana" (Official Mexican Regulation) NOM-31-SSA1 which is similar to standards used in the U.S. Shellfish waters may be classified as "approved", "conditionally approved" and "restricted". The standards for each are described in Figure 1.

In the case of restricted waters, shellfish may still be grown, but must be relayed and depurated in approved water before consumption or sale. For prohibited areas, shellfish should not be consumed nor sold.

Type of test	Classification of Shellfish Growing Ground			
	Approved	Conditionally approved	Restricted	Prohibited
Total coliform bacteria		Conditionally approved waters are those which meet standards for "approved" waters except for occasional, seasonal or intermittent events. Routine monitoring is required with closures indicated when approved levels are exceeded.		Prohibited waters are those which routinely exceed the standards established for "restricted" waters and/or which are contaminated by other dangerous substances such as toxins, biotoxins, radioactivity, etc.
Median or average NMP/100 ml may not exceed:	70 MPN/100ml		700 MPN/100 ml	
No more than 10% of samples may exceed, using a serial dilution (5 tubes):	230 MPN/100 ml		2,300 MPN/100 ml	
No more than 10% of samples may exceed, using a serial dilution (3 tubes):	330 MPN/100 ml		3,300 MPN/100 ml	
Fecal coliform bacteria				
Median or average NMP/100 ml may not exceed:	14 MPN/100 ml		88 MPN/100 ml	
No more than 10% of samples may exceed, using a serial dilution (5 tubes):	43 MPN/100 ml		260 MPN/100 ml	
No more than 10% of samples may exceed, using a serial dilution (3 tubes):	49 MPN/100 ml		300 MPN/100 ml	

Figure 1. Summary of allowable levels of total and fecal coliform bacteria for classified shellfish growing waters in Mexico under NOM-31-SSA1.

Although Mexican regulations and standards have been established, a gap exists in that shellfish growing or fishing areas are rarely monitored. Only in the case of a few estuaries where large commercial farms intend to export to the United States is routine monitoring conducted. In this case, U.S. standards are used. This work was intended to have immediate practical purposes in determining whether the shellfish growing waters of interest to the team of researchers and their extension clients in the estuary communities were adequate to produce a safe, sanitary product. Additionally, through the outreach components of this work, it was hoped that the public as well as key decision-makers and regulators would become more aware of the importance and nature of shellfish sanitation, and measure that could be taken to improve the situation for the benefit of consumers and producers. While the benefits to consumers are clear, a concurrent study (*Bivalve Marketing Study for Pacific Mexico-12 ERA6*) conducted by CRSP-funded economists Dr. Francisco Cordero (CIAD) and Dr. Quentin Fong (FITC/University of Alaska) demonstrated that safe, clean

product was one of the most desirable attributes identified by oyster vendors and that this can confer a higher price for the product.

Study Areas and sampling stations

Study Area 1: Boca Camichin

The Boca Camichin estuary is located in the NE part of the State of Nayarit in the Municipality of Santiago Ixcuintla. Coordinates for this site are 24° 48' al 24° 44' north and 105° 30' al 105° 29' east (Figure 2). Surface area is approximately 200,000 ha extending from the Baluarte River to the Port of San Blas on the San Cristobal estuary. Boca Camichin includes between 15 y el 20% of the total mangrove areas found in Mexico. The two major water sources are the San Pedro River and the Santiago River. Boca Camichin is part of the larger wetland area known as “Marismas Nacionales” (National Wetlands), an area of importance for biodiversity conservation, management and the Mexican economy. It is also the focus for several national and international conservation and management initiatives. The CRSP-funded work was conducted within a broader context of assisting with coastal management efforts for this region. Within Boca Camichin, 30 sampling stations were identified and marked before sampling began (Figure 3).

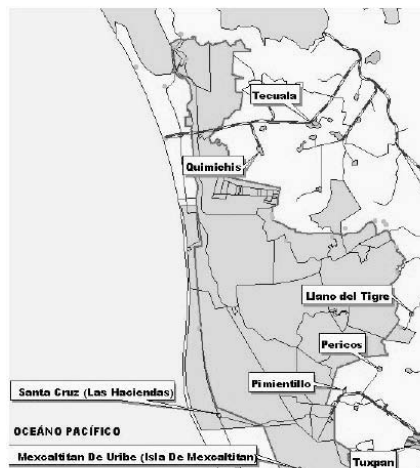


Figure 2. Location of Boca Camichin in Nayarit, Mexico.

Study Area 2: Bahía Santa María de la Reforma

Bahía Santa María de la Reforma (Santa María Bay-BSM) is surrounded by the Municipalities of Angostura and Navolato in the State of Sinaloa. This bay is the largest one on the central Pacific Coast of Mexico and has about 450,000 ha² of water surface area. It is located between 24° 25' and 25° 30' north and 107° 35' y 108° 25' west (Figure 4). BSM receives water from a number of streams and rivers; the principal source is the Mocorito River which drains an extensive watershed containing agricultural, urban and industrial areas. BSM is an important biodiversity conservation site and has been the focus of coastal management efforts for over 12 years by UAS, URI, UHH and local stakeholders, among others. Management of the Bay is currently the legal mandate of the BSM Bay Management Committee. Additionally, BSM is important as a site of several regionally important fisheries (finfish, crabs and shrimp) and large shrimp farms. Forty sampling stations were identified and marked within BSM for water quality monitoring (Figure 5). Station selection was made on the basis of the location of existing and future oyster farming sites.

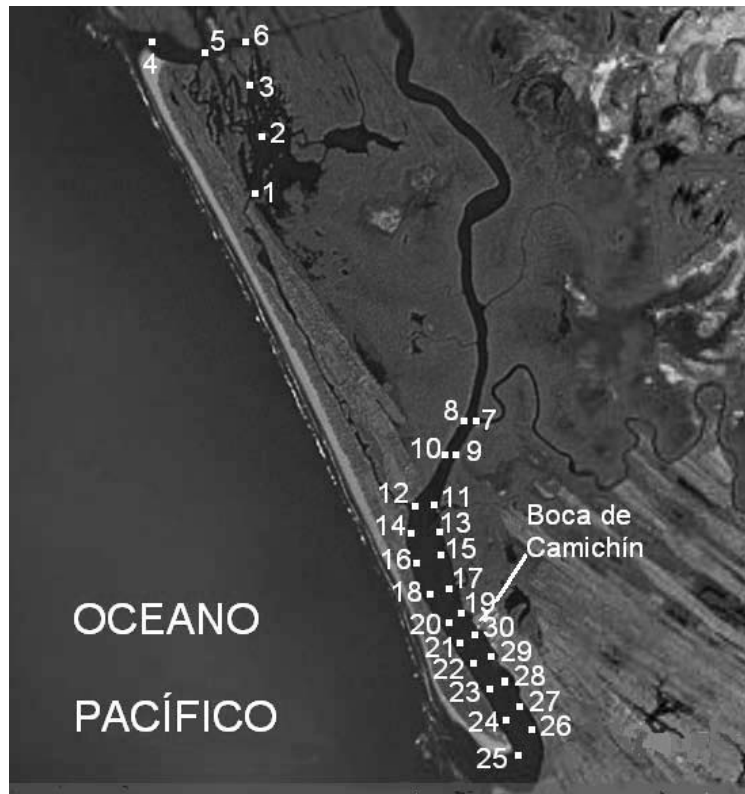


Figure 3. Locations of sampling stations at Boca Camichín estuary, in Nayarit, México.

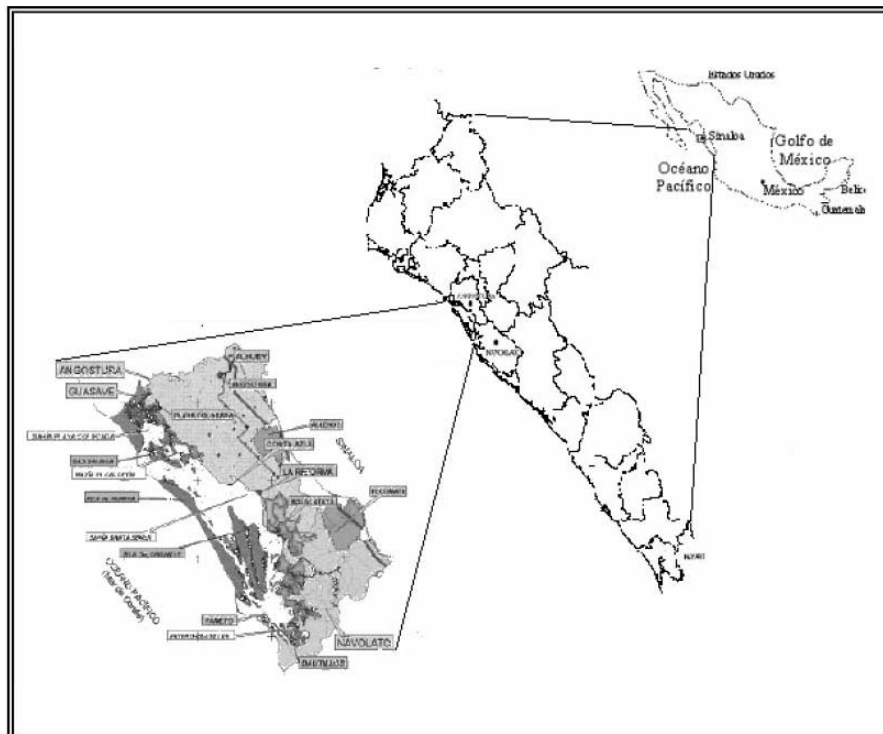


Figure 4. Location of Santa Maria Bay in Sinaloa, Mexico.



Figure 5. Location of water quality sampling stations in BSM.

METHODS

Sampling

Water samples were collected in previously sterilized vials. The samples were taken by completely submerging the vial and filling it facing the current at 20 cm depth. Vials were stored in sterile plastic bags and kept on ice during transportation to the laboratory at the School of Marine Sciences, UAS, Mazatlan, Mexico where they were subsequently stored below 10 °C.

Laboratory analysis

Analysis was conducted utilizing the Most Probable Number method required by the NOM-031-SSA1-1993.

Presumptive Test

Water samples are agitated and serial dilutions are made using three tubes containing lactose bile broth for each dilution. These are then incubated at 35 °C for 24 ± 2 hours and examined for the formation of gas; if gas was not detected, then incubation was extended to 48 ± 2 hours.

Confirmed Test

For each tube in which gas is formed, a portion of the suspension was transferred into an equal number of tubes containing Brilliant green lactose bile (BGLB) media. These were incubated at 35 °C for 24 ± 2 hours; if no gas is formed, incubation was extended to 48 ± 2 hours. The MPN was then calculated for coliforms based on the proportion of confirmed gassing tubes for 3 consecutive dilutions (Table 1).

Table 1. For 3 tubes each at 0.1, 0.01, and 0.001 g inocula, the MPNs per gram and 95 percent confidence intervals (FDA 2007).

combination of positives	3 tube, serial dilution		
	Index	95 % confidence	
	of MPN per g	intervals low high	
0-0-0	<0.03	<0.005	<0.09
0-0-1	0.03	<0.005	<0.09
0-1-0	0.03	<0.005	0.13
0-2-0			
1-0-0	0.04	<0.005	0.20
1-0-1	0.07	0.01	0.21
1-1-0	0.07	1.01	0.23
1-1-1	0.11	0.03	0.36
1-2-1	0.11	0.03	0.36
2-0-0	0.09	0.01	0.36
2-0-1	0.14	0.03	0.37
2-1-0	0.15	0.03	0.44
2-1-1	0.20	0.07	0.89
2-2-0	0.21	0.04	0.47
2-2-1	0.28	0.10	1.50
2-3-0			
3-0-0	0.23	0.04	1.20
3-0-1	0.39	0.07	1.3
3-0-2	0.64	0.15	3.80
3-1-0	0.43	0.07	2.1
3-1-1	0.75	0.14	2.3
3-1-2	1.20	0.30	3.8
3-2-0	0.93	0.15	3.80
3-2-1	1.50	0.30	4.40
3-2-2	2.10	0.35	4.70
3-3-0	2.40	0.36	13.0
3-3-1	4.60	0.71	24.0
3-3-2	11.0	1.50	48.0
3-3-3	>11.0	>1.50	>48.0

RESULTS

Study Area 1: Boca Camichin

Total Coliform Bacteria

Concentrations of Total Coliform Bacteria

For the first sampling period of February 2006, 87% of the water samples had bacteria concentrations lower than 100 MNP/100 ml and only 6.6% (2 of 30 samples) had levels over 330 MPN/100 ml. The highest number of samples fell into the 40-60 MPN/100 ml range with a second peak for the interval 80-100 MPN/100 ml. The geometric mean for the 30 samples was 71.7 MPN/100 ml and the median was 75 MPN/100 ml. For the samples collected in July 2006, the distribution of bacterial concentrations was wider, ranging from zero to > 330 MPN/100 ml, with

a slightly higher percentage (13.3%) of the samples exceeding 330 MPN/100 ml. The highest percentage of samples corresponded to the interval of 140-160 MPN/100 ml. The geometric mean was 125 MPN/100 ml and the median was 150 MPN/100 ml. For the samples collected in July 2006, the pattern of distribution of the concentrations was similar to that found for the samples from September with values ranging from zero to more than 330 MPN/100 ml. The highest percentage of samples fell into the interval of 100-120 MPN/100 ml. The geometric mean was 135 MPN/100 ml and the median was 110/100 ml. For samples taken in December 2006, the distribution of samples fell into a wide range of concentration intervals, with the majority (87%) having concentrations greater than 80 MPN/100 ml. The highest percentage of samples fell into the interval of 80-100 MPN/100 ml and 13.3% exceeded 330 MPN/100 ml. The geometric mean was 129 MPN/100 ml and the median was 110 MPN/100 ml. For the final sampling period (January 2007), 47% of the samples contained concentrations lower than 60 MPN/100 ml and 53% had concentrations between 80 and 240 MPN/100 ml. The highest percentage of samples fell into the range of 0-20 MPN/100 ml and no samples had concentrations greater than 33 MPN/100 ml. The geometric mean was 54 MPN/100 ml and the median was 93 MPN/100 ml (Figure 6).

Comprehensive analysis of samples

For all samples collected from January 2006 to January 2007, 70% had a concentration of total coliform bacteria greater than 100 MPN/100 ml and 10% exceeded 330 MPN/100 ml. The geometric mean was 97.2 MPN/100 ml and the median was 110 MPN/100 ml (Figure 7).

Shellfish growing water classification

When considering results from all sampling dates, bacterial levels were such that standards for approved shellfish growing grounds were exceeded since the median and geometric mean exceeded 70 MPN/100 ml. Although levels for February 2006 and January 2007 were below the established standards, the overall mean and median still exceeded the standards. With these results, Boca Camichin would be classified as *a restricted area for bivalve cultivation*.

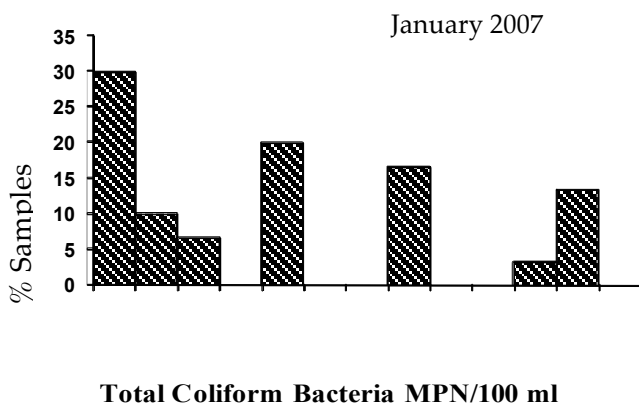
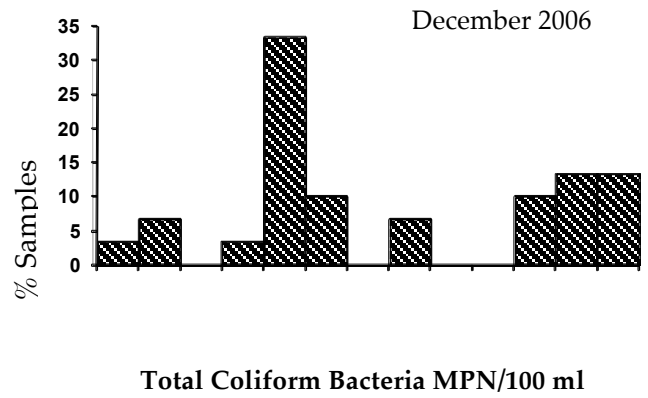
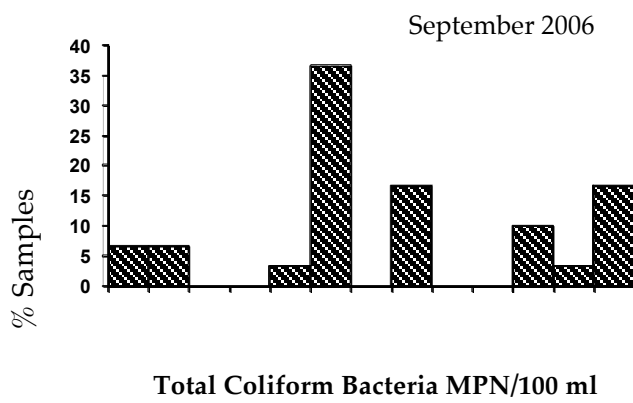
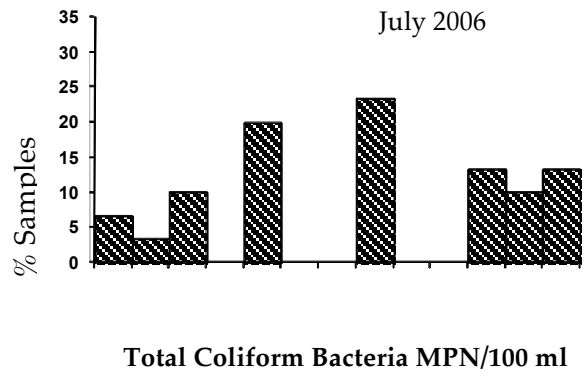
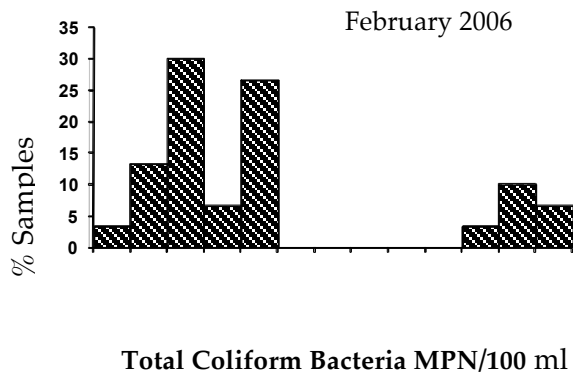


Figure 6. Percentages of water samples from Boca Camichin with corresponding levels of Total Coliform Bacteria (MPN/100 ml)

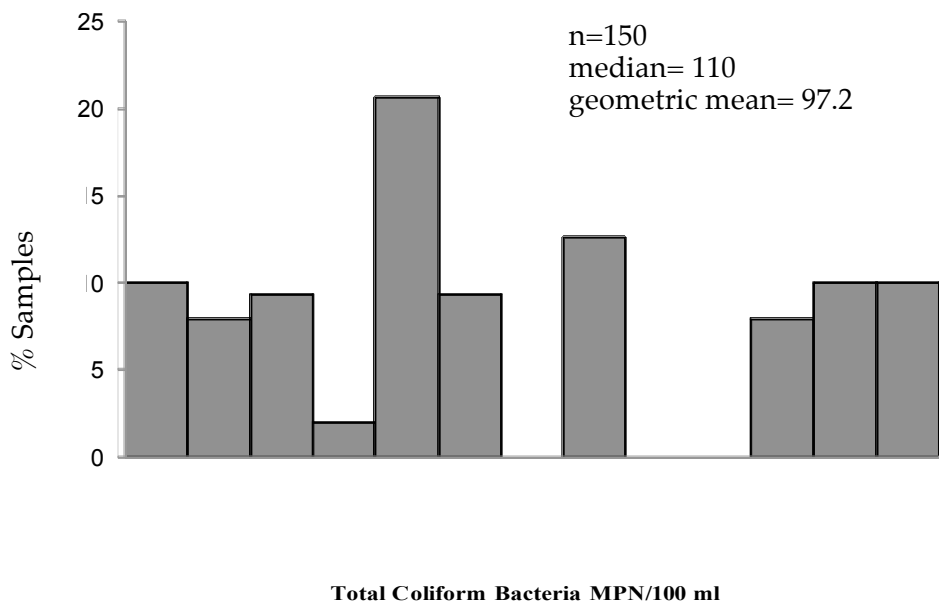


Figure 7. Percentage of samples from all sampling periods and concentration ranges for Total coliform bacteria.

Table 2. Summary of total coliform bacteria levels and classification of shellfish growing area for Boca Camichin.

Date	n	Median	Mean	Standard For Approved Area	% of samples > 330 MPN/100 ml	Standard For Approved Area	Classification of Area	Salinity (ppm)
Feb. 06	30	75	71.7	< 70	6.6	<10%	Restricted	29.1
July 06	30	150	125.3		13.3		Restricted	14.5
Sept. 06	30	110	134.8		16.6		Restricted	4.2
Dec. 06	30	107	125.4		13.3		Restricted	31.6
Jan. 07	30	93	55		0		Restricted	30

Study Area 1: Boca Camichin

Fecal Coliform Bacteria

Concentrations of Fecal Coliform Bacteria

For the sampling period of February 2006, 54% of the samples had a concentration of fecal coliform bacteria between zero and 12 MPN/100 ml, with the highest percentage of samples falling in the interval of 8-12 MPN/100 ml. For 37% of the samples, concentrations were 12-44 MPN/100 ml and 10% had concentrations greater than 49 MPN/100 ml. The geometric mean was 16.7 NMP/100 ml for all samples and the median was 10.5 MPN/100 ml. For samples collected in July 2006, 48% of the samples had concentrations between zero and 16 MPN/100 ml. Forty-two percent had concentrations of 16-44 MPN/100 ml and 10% had a concentration greater than 49 MPN/100 ml. The geometric mean was 20.3 MPN/100 ml and the median was 20.5 MPN/100 ml. For the sampling period of September 2007, 70% of the samples had a concentration greater than 49 MPN/100 ml, with 22% having concentrations of 20-44 MPN/100 ml and only 8% with concentration less than 16 NPM/100 ml. The geometric mean was 20.3 MPN/100 ml and the median was 20.5 MPN/100 ml. For December 2006, all samples had concentrations greater than 12 MPN/100 ml, with the highest percentage of samples falling into the ranges of 20-24 MPN/100 ml, 40-44 MPN/100 ml or greater than 49 MPN/100 ml. Twenty-seven percent of the water samples had concentrations greater than 49 MPN/100 ml. The geometric mean was 39.8 MPN/100 ml and the median was 41 MPN/100 ml. For the sampling periods of January 2007, 76% of the samples had concentrations less than 24 MPN/100 ml with the highest percentage of samples in the range of 0-4 MPN/100 ml. Ten percent of the samples exceeded 49 MPN/100 ml. The geometric mean was 15.7 MPN/100 ml and the median was 12 MPN/100 ml (Figure 8).

Comprehensive analysis of samples

For all samples collected from February 2006 to January 2007, 64% had concentrations greater than 16 MPN/100 ml and 25% exceeded 330 MPN/100 ml. The geometric mean was 23 NMP/100 ml and the median was 35.8 MPN/100 ml (Figure 9).

Shellfish growing water classification

When considering results from all sampling dates, fecal coliform bacterial levels were such that standards for approved shellfish growing grounds were exceeded since the median and geometric mean exceeded 14 MPN/100 ml and at none of the sampling periods did 10% or less of samples have levels lower than 47 MPN/100 ml (Table 3). According to these results, Boca Camichin would be classified as *a restricted area for bivalve cultivation*. It should be noted that the highest bacterial levels were recorded in September and coincide with the period of lowest salinity.

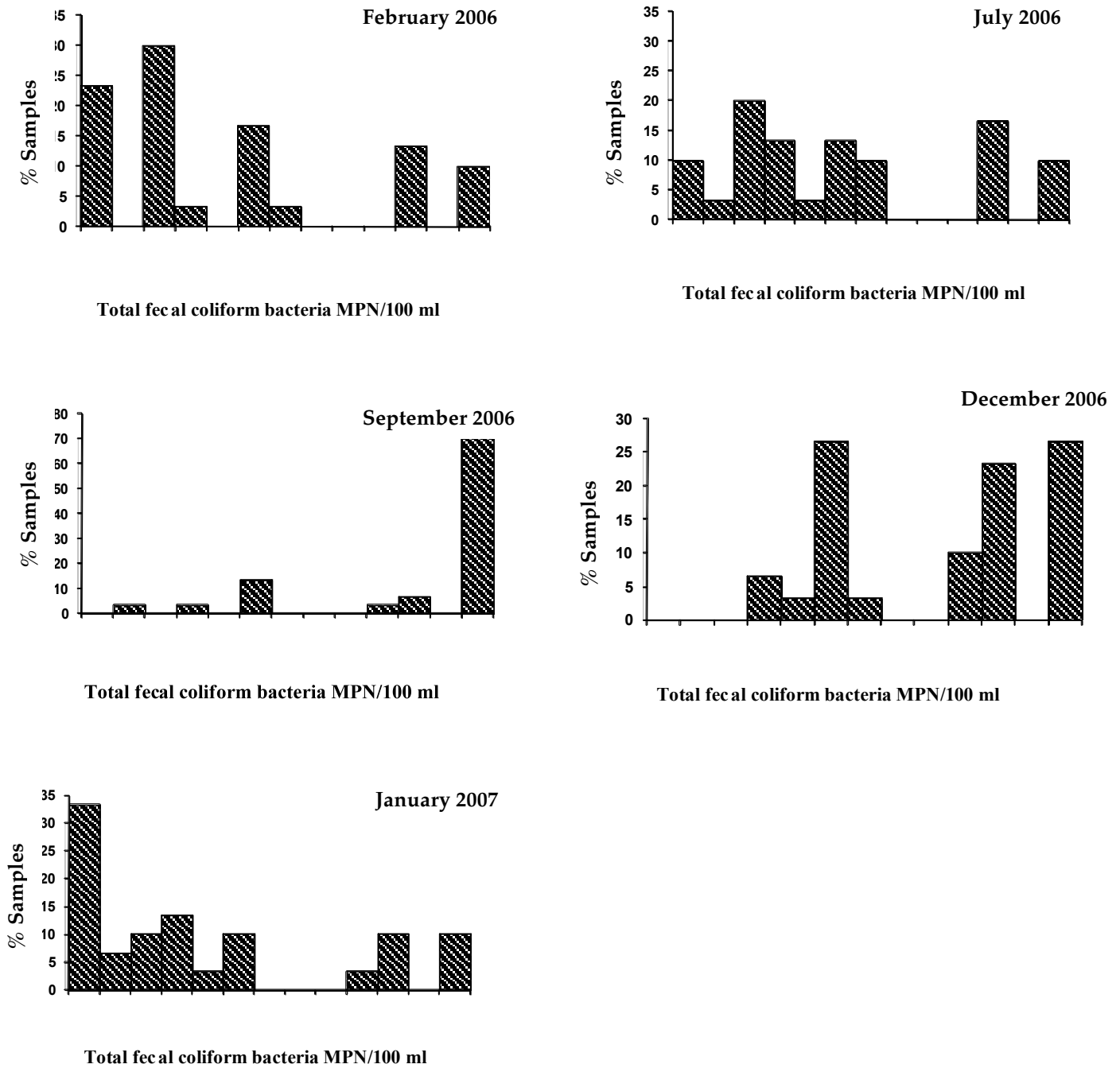


Figure 8. Percentage of samples and ranges of concentrations of fecal coliform bacterial from Boca Camichin.

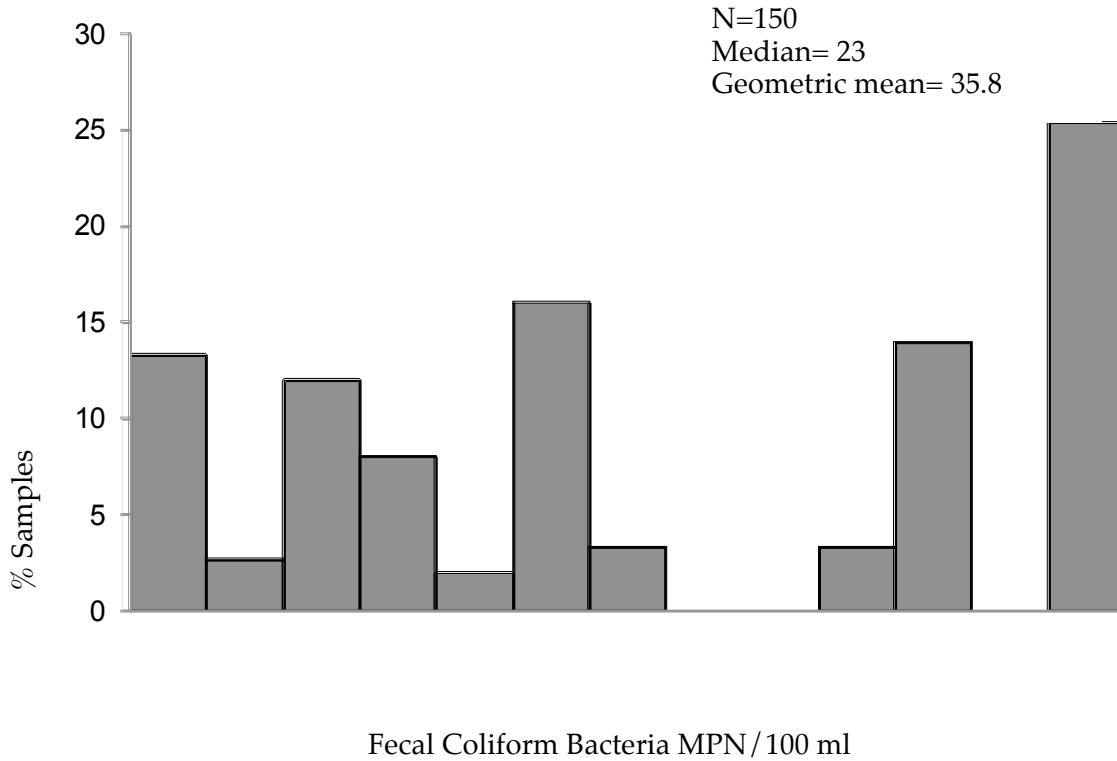


Figure 9. Percentage of sample from all sampling periods according to ranges of concentration of fecal coliform bacteria.

Table 2. Summary of the fecal coliform concentrations and classification of shellfish growing ground for Boca Camichin.

Date	N	Median	Mean	Standard for Approved areas	% of samples with > 47 NMP/100ml	Standard for Approved Areas	Classification of Area	Salinity (ppm)
Feb. 2006	30	10.5	16.7	<14	10	<10%	Restricted	29.1
July 2006	30	20.5	20.35		10		Restricted	14.5
Sept. 2006	30	93	84.62		21		Restricted	4.2
Dec. 2006	30	41	39.82		26.6		Restricted	31.6
Jan. 2007	30	12	15.68		10		Restricted	30

Study Area 2: Bahia Santa Maria Bay

Total Coliform Bacteria

Concentrations of Total Coliform Bacteria

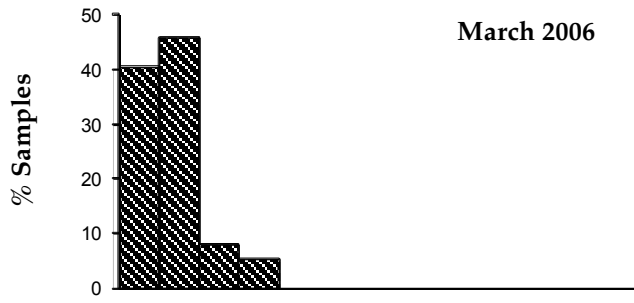
For the first sampling period of March 2006, the concentration of total coliform bacteria was less than 80 MPN/100 ml and 96% of the samples had concentrations between zero and 40 MPN/100 ml. The geometric mean was 18.4 MPN/100 ml and the median was 23 MPN/100 ml. In July 2006, 90% of the water samples had concentrations less than 80 MPN/100 ml and 7.5% exceeded 330 MPN/100 ml. The geometric mean was 26.9 MPN/100 ml and the median was 23 MPN/100 ml. For October 2006, the samples' concentrations varied between zero and 240 MPN/100 ml, but 78% of these were less than 100 MPN/100 ml. Six of the 37 samples had relatively high concentrations between 140 and 160 MPN/100 ml, but none of the samples exceeded 330 MPN/100 ml. The geometric mean was 50 MPN/100 ml and the median was 43 MPN/100 ml. In December 2006, 86% of the samples had concentrations less than 80 MPN/100 ml and only one sample (2.7%) had a concentration greater than 330 MPN/100 ml. The geometric mean was 19.4 MPN/100 ml and the median was 23 MPN/100 ml. For the final sampling period in January 2007, 97.3% of the samples had concentrations less than 60 MPN/100 ml and only one sample (2.7%) had a concentration of 80-100 MPN/100 ml (Figure 10).

Comprehensive analysis of samples

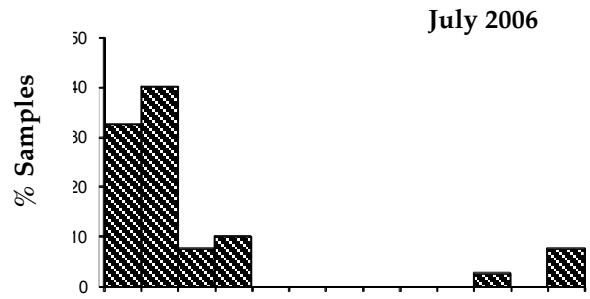
For all samples collected between March 2006 and January 2007 (n=187), 87.3% had concentrations less than 80 MPN/100 ml and only 2.14% had values greater than 330 MPN/100 ml. The geometric mean was 23 MPN/100 ml and the median was 11.26 MPN/100 ml.

Shellfish growing water classification

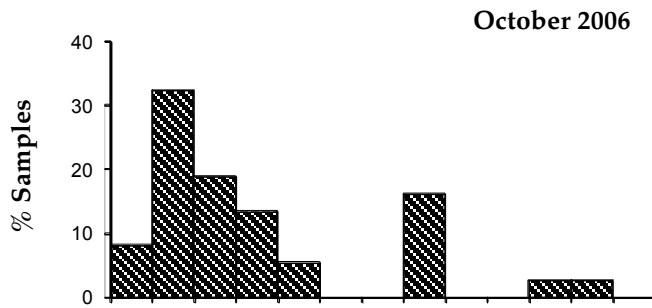
For all sampling periods and for the total sample analysis, the water quality of Santa Maria Bay met established water quality standards since neither the geometric means nor medians exceeded 70 MPN/100 ml and less than 10% of the samples exceeded 333 MPN/100 ml. According to these results, this area would be classified as "Approved" shellfish growing grounds.



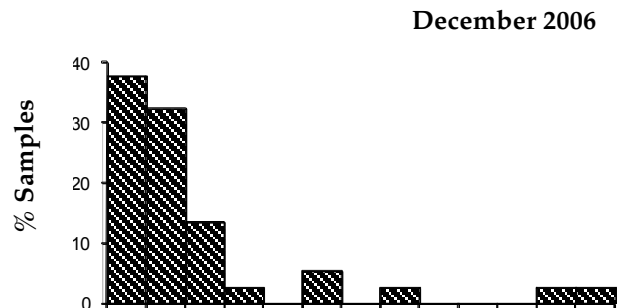
Total Coliform Bacteria MPN/100 ml



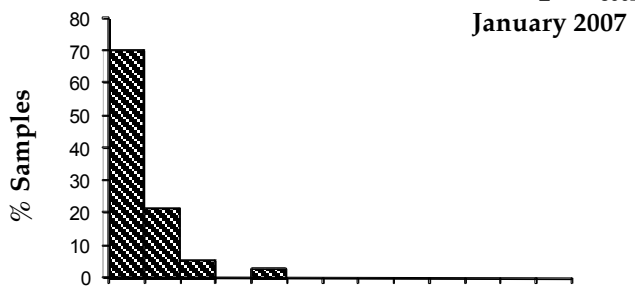
Total Coliform Bacteria MPN/100 ml



Total Coliform Bacteria MPN/100 ml



Total Coliform Bacteria MPN/100 ml



Total Coliform Bacteria MPN/100 ml

Figure 10. Percentage of water samples by concentration ranges for total coliform bacteria for Santa Maria Bay.

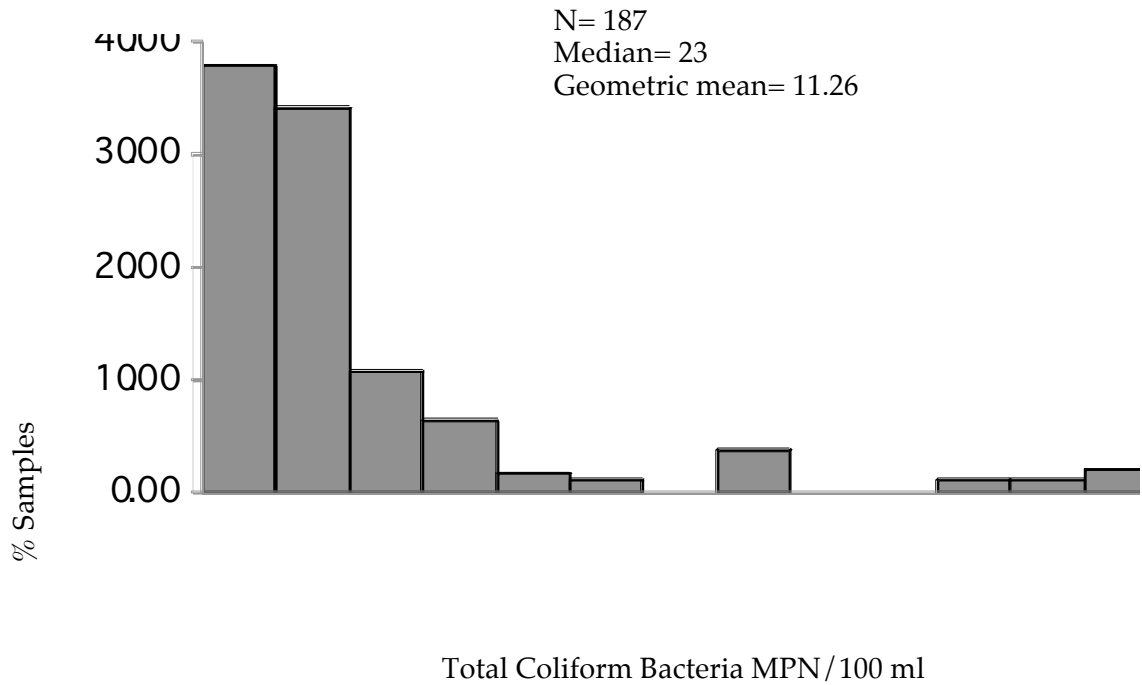


Figure 11. Percentage of samples for the entire sampling period according to concentration of total coliform bacteria for Santa Maria Bay.

Table 3. Summary of total coliform bacteria and area classification for Santa Maria Bay.

Date	N	Median	Mean	Standard for Approved areas	% of samples with > 47 NMP/100ml	Standard for Approved Areas	Classification of Area	Salinity (ppm)
Mar. 2006	30	23	18.4	<70	0	<10%	Approved	35
July 2006	30	23	26.9		7.5		Approved	38
Oct. 2006	30	43	50.15		0		Approved	29
Dec. 2006	30	23	19.3		2.7		Approved	36
Jan. 2007	30	9	11.26		0		Approved	35

Study Area 2: Bahia Santa Maria Bay

Fecal Coliform Bacteria

Concentrations of Fecal Coliform Bacteria

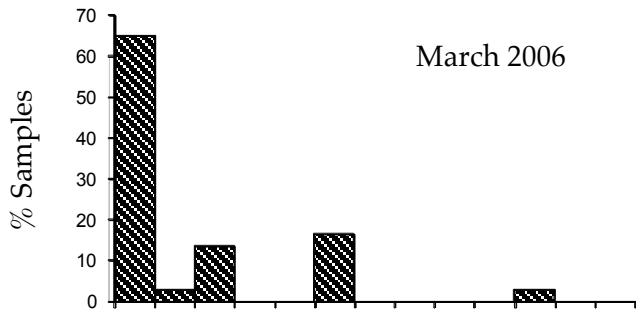
In March of 2006, 81% of samples collected had fecal coliform bacteria levels less than 12 MPN/100 ml and 6 samples had levels of 20-24 MPN/100 ml. None of the samples exceeded 47 MPN/100 ml. The geometric mean was 7.9 MPN/100 ml and the median was 4 MPN/100 ml. For samples collected in July 2006, 97% of samples had concentrations less than 12 MPN/100 ml and the majority (80%) were between zero and 4 MPN/100 ml. The geometric mean was 5.2 MPN/100 ml and the median was 4 MPN/100 ml. Eighty-four percent of samples collected in October 2006 had concentrations between zero and 4 MPN/100 ml and the maximum concentration was 12 MPN/100 ml. The geometric mean was 4.5 MPN/100 ml and the median was 4 MPN/100 ml. For samples collected in December 2006, all had concentrations of 9-16 MPN/100 ml with the greatest frequency being in the range of zero to 4 MPN/100 ml. The geometric mean was 5.7 MPN/100 ml and the median was 0 MPN/100 ml. For January 2007, 94.6% of the samples had concentrations between zero and 4 MPN/100 ml and the rest were between 8-12 MPN/100 ml. The geometric mean was 5.2 MPN/100 ml and the median was zero MPN/100 ml (Figure 12).

Comprehensive analysis of samples

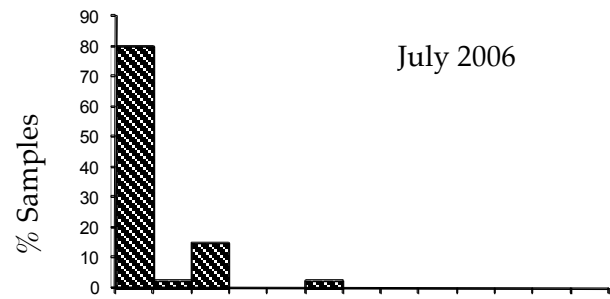
For samples collected over the entire sampling period, 187 (95%) had concentrations between zero and 12 MPN/100 ml, with the highest frequency (80%) falling between zero and 4 MPN/100 ml. The geometric mean was 5.2 MPN/100 ml and the median was 4 MPN/100 ml (Figure 13).

Shellfish growing water classification

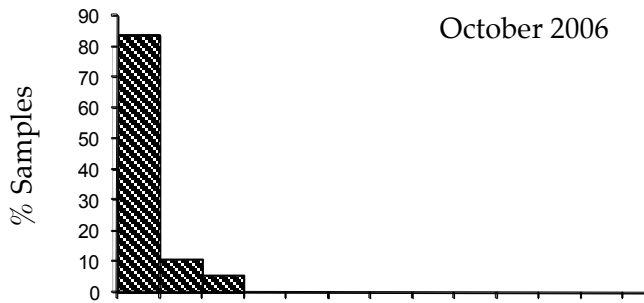
Both the geometric mean and the median concentration of fecal coliform bacteria was less than 47 MPN/100 ml ranging between zero and 8 MPN/100 ml. These levels are less than the established standards and therefore the sampled areas in Santa Maria Bay would be classified as "Approved" shellfish growing grounds (Figure 14).



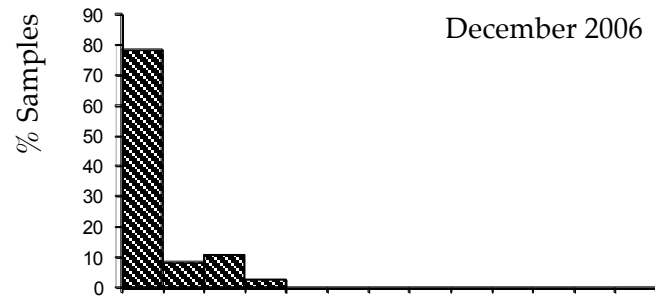
Fecal Coliform Bacteria MPN/100 ml



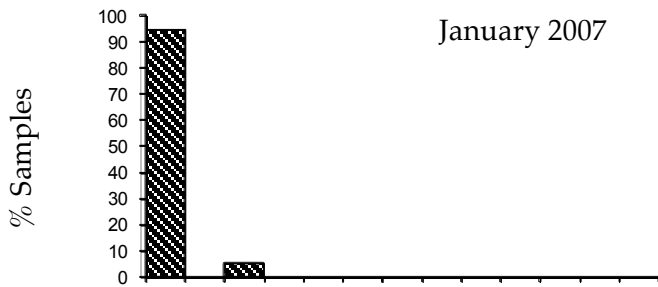
Fecal Coliform Bacteria MPN/100 ml



Fecal Coliform Bacteria MPN/100 ml



Fecal Coliform Bacteria MPN/100 ml



Fecal Coliform Bacteria MPN/100 ml

Figure 13. Percentage of samples and frequencies of concentrations for fecal coliform bacteria from Santa Maria Bay.

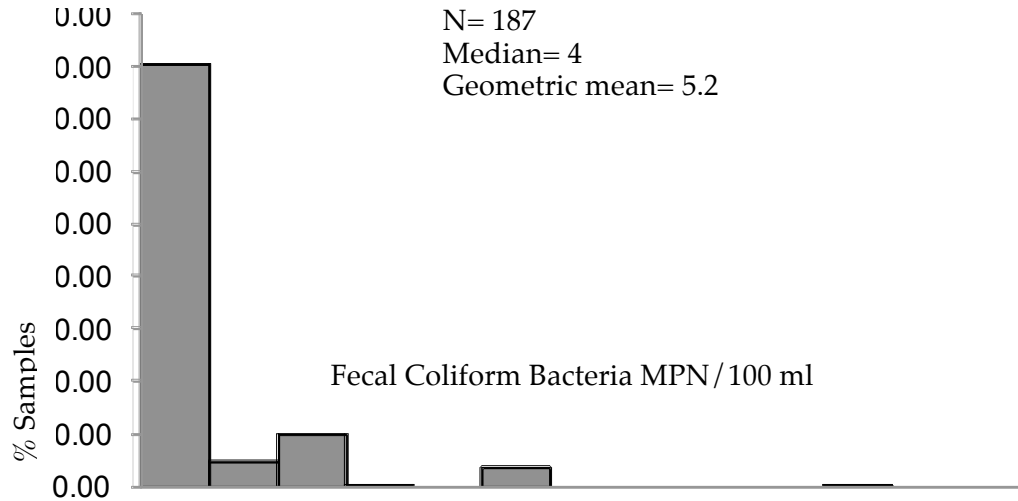


Figure 13. Percentage of all samples by frequency of concentration of fecal coliform bacteria for Santa Maria Bay.

Table 4. Summary of fecal coliform bacteria levels and area classification for Santa Maria Bay.

Date	N	Median	Mean	Standard for Approved areas	% of samples with > 47 NMP / 100ml	Standard for Approved Areas	Classification of Area	Salinity (ppm)	Implications of Water Quality Monitoring Results and
Mar. 2006	30	37	7.9	<47	0	<10%	Approved	35	
July 2006	30	37	5.2		0		Approved	38	
Oct. 2006	30	37	4.5		0		Approved	29	
Dec. 2006	30	37	5.7		0		Approved	36	
Jan. 2007	30	37	5.2		0		Approved	35	

Classification of Shellfish Growing Waters

Boca Camichin is the site of a thriving oyster culture industry where the farms are owned and operated by small cooperatives. The results of this study indicate high levels of contamination of the growing grounds which pose a risk to human health and possibly the ability to sell the product. The oysters are also consumed locally and regionally, with potential broad scale impacts. This contamination is most likely the result of the lack of community sanitation in the town that borders the growing area. Given that the area is so heavily contaminated and because immediate solutions are will not be easy to implement, the quickest solution is to begin using relay and depuration strategies. This will involve moving the oysters to the growing grounds with clean waters 2-3 weeks before sale and holding them in these waters until pathogen levels can be reduced. This is a common method used in the U.S. in many locations. The FDA requires a minimal time in the clean waters of two weeks. Future work will focus on developing a cost-

effective methods for relay and depuration. At the same time, the team involved in this work will work closely with the community and the Boca Camichin Committee for Conservation and Management to begin working towards improved community sanitation as the team has successfully done in several communities located near Santa Maria Bay.

In the case of Santa Maria Bay, all the sampled areas would be classified as “Approved” shellfish growing grounds as contamination is present in only very low levels. This is reassuring for current oyster growers, although care must be taken to prevent future contamination and to continue routine monitoring. The areas projected for future oyster growing projects led by the team with fisher and women’s groups are also adequate for shellfish culture, so these projects can move ahead. Additionally, the possibility exists to begin working with Mexican authorities and the U.S. FDA to monitor and classify these areas for export to the U.S.

Student Training

Four students were involved in this work.

Jorge Alberto Ruiz García, student at UAS, participated in this research and wrote his thesis on the topic, “Classification of waters at Santa Maria Bay for the culture and extraction of bivalves”.

José Guadalupe Olivo Rojas, student at UAS, participated in this research and wrote his thesis on the topic, “Classification of waters at Boca Camichin, Nayarit, Mexico for the culture and extraction of bivalves”.

At UH-Hilo, three students provided support including Daren Gariques (undergraduate, Ecuador), Joao Gariques (undergraduate, Ecuador) and Abelardo Rojas (Masters Degree candidate, Nicaragua). They provided assistance with library research, data management and project management.

At LSU, Masters Degree Candidate Roberto Quintana (Mexico) provided support to Dr. John Supan and the research team for issues of shellfish sanitation and translation.

Public Involvement and Outreach

This work was approached as a form of participatory research. In both study areas, meetings were held with stakeholders before and after each sampling period to discuss the research and its significance, and to report results from previous sampling periods. Training was provided in how to conduct water sampling and the importance of shellfish sanitation.

Multiple public institutions were involved in outreach meetings and presentations including the Federal Commission for Protection Against Sanitary Risks (COREPRIS); the National Commission for Aquaculture and Fisheries (CONAPESCA); the State Governments for Nayarit and Sinaloa; three Municipal Governments; The State Committee for Aquaculture Sanitation of Nayarit (CESANAY); The State Committee for Aquaculture Sanitation of Sinaloa (CESASIN); the Technological University of the Coast; the Autonomous University of Nayarit (UAN); and the two Conservation and Management Committees for the two estuaries.

From April to November 2006, three workshops were planned to form working groups for shellfish sanitation and culture issues and to develop an integrated management plan for Boca Camichin. Outcomes include formation and official recognition of the working groups, development of the management plan, strategies for obtaining funding to implement components of the management plan, and some preliminary implementation. Since August 2007, five additional meetings of the Committee for Development and Conservation of Boca Camichin (CCDEBC) have been held to continue the work. Among implementation activities were the obtention of a grant to fund some preliminary work on oyster culture with poor stakeholder groups in Santa Maria Bay and a series of meetings were held with these stakeholders as well.

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

Twelfth Work Plan, Aquaculture & Human Health Impacts 2 (12AHH2)
Final Report
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ABSTRACT

This investigation is part of a larger effort to elucidate relationships between human health, water resources and aquaculture status and development in the States of Sinaloa and Nayarit, Pacific Mexico Coast. Culture of oysters (*Crassostrea corteziensis* and *C. gigas*) and other bivalves is an important industry for small-holder aquaculture along the Pacific Mexico Coast, but shellfish sanitation issues are a key impediment to expanding and improving this form of aquaculture. Improving the policy, regulation and implementation of adequate shellfish sanitation will positively impact both human health and the economic welfare of coastal communities. As efforts to diversify aquaculture through strengthening of shellfish culture are underway and as consumer awareness of the potential dangers of consuming aquatic products increases, measures to assure the production of safe shellfish and other aquaculture products are needed.

This work achieved four principal objectives. The first was to disseminate the results of research conducted as part of Investigation 12AHH1, "*Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters.*" This research involved water quality monitoring of two significant bivalve growing sites in Nayarit and Sinaloa states where the oyster species *Crassostrea corteziensis* (Pleasure Oyster) and *Crassostrea gigas* (Japanese oyster) are cultured, and outreach was required to convey the purpose of the studies and final results to oyster growers and institutional stakeholders. Informational workshops were therefore held before and after each periodic water sampling during a period of one year. Secondly, results from previous CRSP sponsored research also required dissemination and these results were included in all the workshops conducted as part of this investigation. Thirdly, it was deemed important to work with two multi-institutional working groups, the Management Committee for Bahia Santa Maria (BSM) and the Council for Conservation and Development of the Camichin Estuary (CCDCE) which are comprised of representatives from public and private institutions as well as stakeholders drawn from important stakeholder groups such as fishers, women's groups and aquaculture farmers, to conduct awareness raising as to the nature of shellfish sanitation, problems that were occurring and to find solutions to these issues. Fourthly, a component of capacity building was included for Latin American students at the University of Hawaii Hilo and Louisiana State University as a means of partially addressing the lack of capacity for shellfish

culture and sanitation in Latin America. Additional awareness raising activities were also conducted such as a Regional Workshop for Shellfish farmers and attendance of project Principal Investigators at international conferences to present research findings.

INTRODUCTION

This work was initiated in early 2006, ending in September 2007. The primary focus of this work is to conduct awareness raising activities to disseminate findings of CRSP-sponsored research related to Human Health and Aquaculture, including shellfish sanitation issues, to a wide variety of stakeholders. Additionally, it was important to not only disseminate results, but to develop action agendas to address problems and take advantage of opportunities presented in coastal areas of Mexico. The work also had a capacity building component for shellfish farmers and Latin American students.

This work was designed to disseminate the results of the following CRSP-sponsored research and capacity building efforts.

From the Year 11 Workplan:

Case studies on Human Health and Aquaculture:

Food Safety and Handling: Increasing Local Consumption of Aquaculture Products and Improving Quality (11DPPR1)

Analysis of Critical Points in Aquaculture Production

Affecting Participation and Level of Benefits to Women, Youth, and Disadvantaged Stakeholders (11AHHR3)

Connectivity of Water Resource Status, Environmental Quality, Aquaculture, and Human Health (11AHHR2)

From the Year 12 Workplan, studies which were conducted concurrently:

Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters (12AHH1)

Bivalve Marketing Study for Pacific Mexico (12 ERA6)

Although information and results from all the above studies was included in outreach efforts, the focus for this work was to provide a better understanding of the issues and opportunities associated with shellfish sanitation in Mexico. Bivalve shellfish are among the species which are easiest to culture and the most nutritious, but can also present the most significant risk for consumers because of the danger of shellfish-borne pathogens (e.g. *Salmonella*, *Hepatitis A*, *E. coli*), presence of toxins from red tides, tendency to accumulate heavy metals and vulnerability to post-harvest contamination. At the same time, Mexico's shellfish industry is an important contributor to local communities' economies and nutrition, and offers tremendous potential for growth in terms of volume of production and diversification of species. The Mexican government has also prioritized shellfish and tilapia as the primary species groups for aquaculture diversification. Additionally, shellfish are particularly important for groups such as women and children who rely upon them for daily food and income.

In the United States, shellfish sanitation is regulated by the Food and Drug Administration in conjunction with the Interstate Shellfish Sanitation Committee. The latter is comprised of representatives from each state's responsible agencies and develops and updates standards and procedures which are uniformly adopted and applied throughout the country. Monitoring of shellfish growing waters over many years has led to an information base that allows for classification of shellfish growing areas in the U.S. Mexico has similar bacteriological standards for shellfish sanitation, but is not actively classifying shellfish growing waters. An additional issue is the complexity of having Mexico shellfish growing waters classified as acceptable by the FDA thus allowing export of shellfish to the U.S., an opportunity many producers would like to take advantage of. At this time, only two areas in Baja California, Mexico are approved for export of shellfish to the U.S.

This work was conducted in close collaboration with two coastal management initiatives for Bahia Santa Maria (Sinaloa) and for the Marisma Nacionales (Nayarit). Both areas are critical and important wetland areas for Mexico; for example, Marismas Nacionales contains 80% of Mexican mangrove areas. At Bahia Santa Maria (BSM), management is the responsibility of the BSM Management Committee and in the case of the study site, Boca Camichin, a major oyster culture area located in a small estuary which is part of the Marismas Nacionales, the responsible group is the Council for Conservation and Development of the Camichin Estuary (CCDCE). Thus much of this work was conducted in collaboration with these multi-institutional groups and with individual groups who participate in the management committees such as fisher, women's and aquaculturist associations.

MATERIALS AND METHODS

Much of this work was done in series of meetings and site visits with various stakeholder groups.

As part of the Investigation 12AHH1, *“Water Quality Monitoring and Identification of Pollution Sources Leading towards Classification of Bivalve Growing Waters,”* periodic water sampling at shellfish growing grounds at BSM and Boca Camichin was conducted approximately every other month for a period of twelve months. Prior to, and after each sampling, community meetings were held during which the rationale, methods and results were discussed with the community members participating in the work. This effort was approached as a participatory research effort meaning that community members were involved in every phase of the work except for the laboratory analysis of the samples. As a result, community members understood and supported the work, and assisted with the sampling. Equally important, they also were able to understand complex issues such as bacteriological standards, relevance to food safety and factors which were leading to pollution of shellfish growing grounds and potentially affecting their livelihoods.

A series of meetings were held with the two major management committees at BSM and Boca Camichin to raise awareness of the issues related to human health, shellfish sanitation and the environment.

A series of meetings was held with stakeholder groups including women's groups interested in, or already conducting shellfish farming, fishers groups and community development groups. The latter were involved in community clean up and hygiene efforts that could affect overall sanitation and water pollution measures.

A regional workshop, *“Exchange of experiences and formation of linkages for social sector oysters farmers”* was held in Culiacan, Sinaloa at the Autonomous University of Sinaloa (UAS) for 56 farmer participants as well as private and public sector stakeholders, although most participants were oyster farmers from Sinaloa and Nayarit.

Assistance by the PIs was also rendered to Drs. Quentin Fong and Francisco Cordero to facilitate their work on CRSP Investigation, *“Bivalve Marketing Study for Pacific Mexico (12 ERA6)”* through introducing them to shellfish farmers and vendors in BSM.

Three of the project personnel also attended the CRSP/World Aquaculture Society Meetings held in San Antonio, TX and two presentations were made at this meeting.

Capacity building for Latin American students in topics related to shellfish farming and sanitation was an important component of this work. Three LAC students were trained in a broad spectrum of skills related to hatchery production of bivalves, grow-out, shellfish sanitation as well as international project management at the Pacific Aquaculture and Coastal Resources Center, University of Hawaii Hilo. Three undergraduate students, two from Ecuador (Daren Garriques

and Joao Garriques) and one from Mexico (Jorge Suriano) were involved in this work. The two students from Ecuador continued to be employed at UHH in aquaculture work up until early 2008 and will continue for the foreseeable future, and the student from Mexico was trained and employed for 6 months, until he suffered from a back injury and had to seek less strenuous employment. Additionally, a Masters student from Louisiana State University, Roberto Quintana (Mexican citizen), was involved in this work and worked with Dr. John Supan to advise on shellfish sanitation issues.

RESULTS AND DISCUSSION

This work has had a wide variety of direct and indirect positive outcomes. Among the results and achievements were the following.

14 community meetings held with stakeholders in BSM and Boca Camichin for purposes of conducting participatory research in water quality monitoring of shellfish growing grounds. Community members now have a better understanding of the issues associated with shellfish sanitation, and linkages to human health and profitability. They also assisted with all phases of the research except for the laboratory analysis, so now have a better understanding of the technical aspects of water quality and shellfish sanitation.

Six meetings were held with the two management committees for the wetland areas, BSM and Boca Camichin. This had multiple outcomes. First, a wide range of stakeholders including government officials, farmers, university personnel, NGOs and community members have a better understanding of the benefits of aquaculture, the advantages of shellfish culture and the general need to improve community sanitation in order to resolve both community health problems but also to improve shellfish sanitation. The Boca Camichin committee have subsequently developed a management plan for the area. This plan contains recommendations and action items to improve shellfish culture and sanitation, as well as general environmental management components that contribute to maintaining the wetlands as natural areas which can also support the aquaculture industry.

Women's groups that process oysters into jarred products and oyster pate gained an improved awareness of steps needed to improve the quality and sanitation of these products as well as measures that could be taken to improve hygiene in small seafood restaurants where many of them also work.

Women's groups in BSM were assisted in fund raising efforts that results in small grants from the State of Sinaloa and an NGO being made so that small oysters farms could be started.

The regional shellfish farmers' workshop was particularly beneficial in that not only was a network formed among previously isolated farmers and technical capability was improved, steps were taken towards forming a regional shellfish farmers association. There were 56 shellfish farmers present as well as a number of other stakeholders (Figure 1).

Two presentations were made at the World Aquaculture Society Meetings and the annual CRSP meeting in San Antonio. One side benefit of this was that discussions were held with an FAO official who may provide some additional funding for activities in shellfish aquaculture in Mexico.

Latin American students were trained in a wide range of technical methods and theory related to shellfish production, hatchery management and project management. Two Ecuadorian students now have 18 and 9 months of hands-on experience, respectively, and one Mexican student gained 6 months of experience. A Mexican graduate student at LSU also gained additional experience in these topics and is now employed as the hatchery manager of a major shellfish operation in Hawaii, which is extending its operations internationally.



Figure 1. Regional shellfish farmers' workshop held at the Autonomous University of Sinaloa in Culiacan, Mexico.

An additional but unforeseen benefit was that due to previous CRSP work which focused on the involvement of marginalized citizens in aquaculture, including the handicapped, is that one of the UAS researchers, Dr. Mario Carranza, a sociologist, continues to send his students to work with the group PROJIMO. This is a group comprised of handicapped persons who work to empower handicapped people through awareness raising, vocational training and medical assistance.

The results of this work also guided a decision by the oyster growers of Boca Camichin to improve community sanitation when the first water sampling events began to reveal that their shellfish growing waters had *E. coli* levels that far exceeded the Mexican standards for approved shellfish growing grounds. Additionally, they are working to relocate their small operations to areas of the estuary which have been shown to have minimal levels of *E. coli* which will improve the safety of the oysters produced.

Presentations and publications resulting from this investigation include:

- Haws, M.C. and J. Supan. 2007. Edible bivalve culture in Hawai'i, bridging the past, present and future: a white paper. Pacific Aquaculture and Coastal Resources Center, University of Hawai'i Hilo.
- Rodriguez-Dominguez, G., E. Gaxiola-Camacho, M.C. Velasquez-Cuadras, J.A. Ruiz-Garcia, J.G. Olivo-Rojas, M.C. Haws and J. Supan. 2007. Classification of Coastal Waters for Bivalve Culture and Fisheries. Abstract. Meetings of the World Aquaculture Society, San Antonio, TX. February 2007.
- Rodriguez-Dominguez, G., E. Gaxiola-Camacho, M.C. Velasquez-Cuadras, J.A. Ruiz-Garcia, J.G. Olivo-Rojas, M.C. Haws and J. Supan. 2007. Human Health and Aquaculture. Aquaculture Fisheries Collaborative Research Support Program Meetings. San Antonio, TX. February 2007.

The shellfish farmers' workshop presentations are archived and were also video-taped for future use.