Pond Dynamics/Aquaculture Collaborative Research Support Program

Fourteenth Annual Technical Report

1 September 1995 to 31 July 1996

Acknowledgments

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I. Introduction

CRSP Research Program Background

In the current reporting period, 1 September 1995 through 31 July 96, the CRSP passed two important milestones: USAID authorization of the PD/A CRSP *Continuation Plan 1996-2001* and completion of activities scheduled under the third grant (originally slated to end in August 1995). The CRSP received a one-year, funded extension from May 1995 through April 1996 which was followed by a three-month, no-cost extension. The Interim Work Plan allowed the successful transition from the third grant, with its focus on production research, to the fourth grant, with its emphasis on aquaculture research that addresses environmental effects and social and economic aspects, as well as production optimization.

When the CRSP lost the Rwasave research site in Rwanda due to civil unrest, the Africa Site Selection Team began looking for a new host country in East Africa. The Sagana Fish Culture Farm in Kenya was recommended as a prime site for CRSP activities in Africa. Negotiations for a Memorandum of Understanding with Kenyan institutions and the PD/A CRSP have progressed and finalization of the agreement is expected in 1997.

The Fourteenth Annual Technical Report is a collection of research reports summarizing activities described in the Seventh and Interim Work Plans. In the following pages readers will note some reports are described as, "Printed as Submitted"; in these instances, editorial changes were limited to the correction of spelling and grammar. The companion to this volume is the Fourteenth Annual Administrative Report, which describes achievements in administration, research, and outreach activities, and includes summaries of program history, staff, finances, and publications. It also contains the abstracts of all technical reports included in this volume.

The CRSP Global Experiment and Related Activities

Since its inception, the goal of the CRSP has been to improve the efficiency of pond production systems through sustainable aquaculture. The strategy adopted by the CRSP in pursuit of this goal has involved the development of a comprehensive research agenda aimed at understanding and improving the efficiency of pond culture systems.

In 1978, a technical plan proposing this strategy was developed under a planning study funded by USAID. The technical plan reviewed and synthesized literature on state-of-the-art pond aquaculture. Overseas sites were surveyed to determined research needs and availability of local support in host countries. The findings from these surveys were then incorporated into planning guidelines.

The literature overview that was conducted during the planning phase showed that different pond systems exhibited considerable variation in productivity. Pond aquaculture had been practiced for centuries as a highly developed art, and the literature was replete with reports about practices that had produced high yields. The results, however, were often not reproducible when the same practices were applied to other ponds. It was clear that there were subtle differences regulating

PD/A CRSP Research Locations Around the World

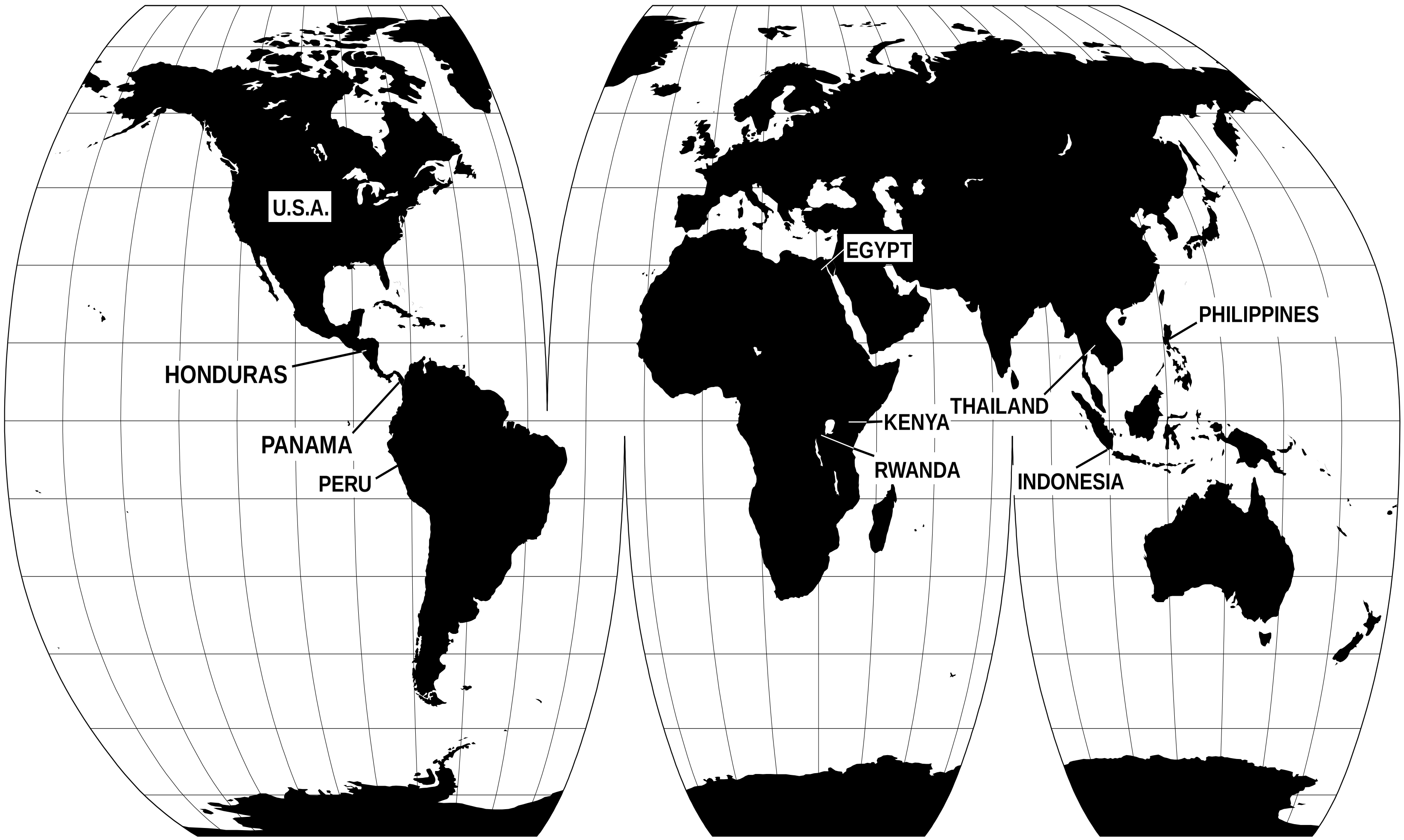

Figure 1. Past and present PD/A CRSP research locations in Latin America (Honduras, Panama, and Peru), Africa (Egypt, Kenya, and Rwanda), Asia (Thailand, Indonesia, and the Philippines), and the United States.

productivity from pond to pond and from site to site, but the nature of these differences remained obscure.

The Global Experiment was intended as a comparative study of aquaculture pond dynamics—one that would begin to explain how and why ponds at different geographic locations function differently, and how the management of those ponds might be adapted to different sets of environmental conditions to optimize production. Hence, a common set of experiments was implemented globally, following a standardized experimental protocol at a number of research sites around the world.

The initial technical design for the Global Experiment involved monitoring environmental and fish production variables at seven locations in six countries. Two brackish water and five freshwater research sites were selected in Central America (Panama and Honduras), Africa (Rwanda), and Southeast Asia (Indonesia, Thailand, and the Philippines) in 1982 (Figure 1). All of the sites were within a zone extending from 15°N to 15°S latitude. These sites represented the three major tropical regions where advances in pond aquaculture would be most beneficial and most apt to succeed. Observations specified in biennial (originally annual) Work Plans were made on twelve or more ponds of similar size at each location. The variables observed, frequency of observation, and materials and methods used were uniform for all locations.

Subsequent changes in 1987, mainly in response to funding constraints, required that research be continued at only three (Thailand, Rwanda, Honduras) of the six countries originally selected and that sites be maintained in the three major regions originally designated. In 1991, the CRSP program was expanded through the initiation of a sub-project in the Philippines (at a new site in Central Luzon) and the beginning of a completely new project in Egypt. Termination of research activities in Panama and funding constraints in 1987 caused a hiatus in brackish water research which was resumed in 1993 with the addition of a new coastal site in Honduras. The outbreak of civil war in Rwanda in April 1994 caused the cessation of all CRSP research activities there. The Egypt project, under a separate grant from the Cairo Mission, was originally slated to end in 1994; however, after a positive review, it was extended for half a year and ended in March 1995.

The first cycle of experiments aimed to develop a set of baseline data on ponds at the various sites. Subsequent Global Experiment studies have focused on investigations of the effects of different fertilizer regimes on pond productivity and yield. In transition to the upcoming fourth grant, in which environmental research took on added emphasis, the focus of the recent Global Experiment was the development of nutrient budgets for specified production regimes in order to determine the environmental effects of effluents.

As CRSP research progressed through the 1980s, questions that differed from site to site and would need to be addressed with specific experiments surfaced. This family of experiments, separate from the standardized Global Experiment, yet performed concurrently with it, is also global in nature. For example, currently all CRSP sites conduct studies on sediment dynamics and their influence on water quality in tilapia or polyculture ponds. Pond soils have been analyzed in an attempt to establish baseline information and to investigate the role of sediments as nutrient sinks. This research dove-tails with the CRSPs interest in the environmental effects of aquaculture on the aquatic environment.

After the first few years of Global Experiment research, economic analyses of pond aquaculture systems were added as a component of the aquaculture development strategy in both the U.S. and host countries. Previous research had relied on many often tenuous assumptions about the dynamic mechanisms regulating pond productivity and confirmed the inadequacy of the existing database. To find out if contemporary pond management practices were in fact the most efficient, CRSP researchers developed production formulas. An extensive comparison of the socioeconomic dimensions of CRSP production techniques among sites is helping CRSP researchers to understand the similarities and differences of socioeconomic influences on their work. A further integration of these research perspectives—environmental effects, social and economic aspects, and production optimization—has been achieved under the PD/A CRSP *Continuation Plan 1996-2001*.

Data Analysis and Synthesis

CRSP planners recognized at the outset that aquaculture ponds are extremely complex ecosystems. This complexity has been reflected in the number of variables and frequency of observations required by the experimental protocols specified in the CRSP Work Plans. Although researchers at each of the overseas field sites are free to analyze their own data and publish their findings, it was recognized that the management and analysis of the global data set (i.e., the data generated by all the field sites) would require the establishment of a central data storage and retrieval system. This Central Database was originally established at Oregon State University and maintained by the Management Entity until Spring of 1993 when it was transferred to the University of Hawaii at Hilo. In May 1996, the Central Database returned to Oregon State University where it is managed by PD/A CRSP researchers in the Department of Bioresource Engineering.

Standardized data are tabulated at each research location in accordance with CRSP Work Plans. At the individual sites, data on physical variables (e.g., solar radiation, temperature, and rainfall) and chemical variables (e.g., water and soil characteristics) are collected concurrently with biological measurements (e.g., primary productivity, fish growth, and fish production). Over 160 physical, chemical, and biological variables (approximately 90,000 observations per site and year) are recorded. Whereas the resulting sets of data are useful for site-specific studies, the compilation of all the individual data sets into the Central Database provides opportunities for many kinds of global analyses. Detailed standardized records such as those found in the CRSP Central Database are rare in the aquaculture literature. An internal review commissioned by the Program Management Office confirmed that all data from research activities conducted under the First through the Fourth Work Plans are already in the database, and entry of data from the Fifth Work Plan is almost completed. The Central Database has continued to expand through the inclusion of new data generated under the Seventh and Interim Work Plans. To facilitate information dissemination the Central Database is now electronically accessible at two locations on the Worldwide Web: the Internet Web Site, http://biosys.bre.orst.edu/crspDB and the worldwide environmental data Web site maintained by the Consortium of International Earth Science Networks (CIESIN). The data search strategy for the Central Database Web Site allows the user to extract and compare any combination of fish production treatments. Other important features of the Database are robustness and flexibility which ensure the inclusion of data generated on new sites.

CRSP participants also decided that the comprehensive analysis and interpretation of global data would be greatly enhanced through the formation of an independent team of researchers who could devote their efforts to this type of analysis. This task force was formally established in 1986 as the Data Analysis and Synthesis Team (DAST). The charge of the DAST is to systematically analyze pond processes and to develop computer models that reflect our growing understanding of pond systems. The DAST members are more than end-users of the database; rather, they participate actively in the design process of the next cycle of Global Experiments. Communication between the DAST and field researchers assures that the experimental design encompasses the information needs of the DAST. The benefits of analyzing global data and synthesizing information into computer models that simulate pond conditions occur on several levels: production management, design, and planning. The quantification of relationships between variables and the effects of different treatments allows farmers to adapt general management techniques to the specific local constraints of climate, water, feed, and fertilizer availability in order to optimize production. The design of production systems will be improved by matching production facilities and costs with production goals. In addition, the models contained in decision support systems developed by the DAST have been useful in estimating fish yields over large geographic regions as part of a large geographic information system currently being developed by the Food and Agriculture Organization of the United Nations.

Special Topics Research

The Special Topics component of the CRSP was created to provide opportunities for host country and U.S. researchers to collaborate on original research directed toward the needs and priorities of each host country. The intent is to strengthen linkages and contribute to the development of research capabilities within host country institutions by providing opportunities for scholarly involvement of faculty and advanced students. This component also provides host country institutions and agencies with access to the human resources of the CRSP in seeking solutions to short-term local problems. Projects focus on specific aspects of the Global Experiment that would benefit from site-specific, detailed investigations.

Proposals for Special Topics Research Projects are developed collaboratively by the host country and U.S. scientists. Once endorsed by the host country institution, proposals are reviewed by the CRSP Technical Committee and other CRSP advisory groups for technical merit and relevance to the general goals of the CRSP. The projects must also be consistent with USAID and host country development strategies and priorities.

Although Special Topics Research Projects are an important part of the CRSP, they are not a major component in terms of funding support or time expenditure. Twenty to 25% of each researcher's time typically is devoted to this activity. The CRSP places high priority on its long-term research agenda. Host country institutions and USAID Missions, however, often consider basic research activities such as the Global Experiment to be of low priority. Consequently, administrators in the host countries sometimes have difficulty justifying participation in the CRSP. The CRSP support for the Special Topics Research activities helps justify the value of their institutions' participation in the CRSP. Special Topics Research was not implemented during this reporting period due to the transitional nature of the research undertaken during the Interim Work Plan.

CRSP Work Plans

From the CRSPs beginning, the Technical Committee of the PD/A CRSP has been responsible for developing technical plans to guide the research efforts of each experimental cycle. During the first three cycles of the program, when global experiments were the main emphasis, CRSP Work Plans were developed annually. The First Work Plan specified a standard protocol for the preparation and stocking of ponds at all locations. Research in the Second Work Plan compared the responses of ponds receiving organic fertilizers with the responses of ponds that received inorganic fertilizers. Experiments described in the Third Work Plan investigated the effects of varying levels of organic fertilizers on pond dynamics.

In response to recommendations of the External Evaluation Panel, a CRSP advisory body, during the first Triennial Review, a biennial approach to Work Plan development and execution was adopted beginning with the Fourth Work Plan. Two-year operating cycles allow more time for completion and evaluation of experiments before plans for the next cycle must be completed.

Although the research program has evolved so that the Global Experiment and site-specific experiments are conducted at the various sites, the concept of a standard protocol for research at all sites has been maintained. The standard protocol was initially introduced as a part of the First Work Plan and has been improved with each subsequent Work Plan. In 1992 it finally evolved into the PD/A CRSPs *Handbook of Analytical Methods*, compiled by the Materials and Method Subcommittee of the Technical Committee and distributed to CRSP participants.

The Fourth Work Plan included tests of specific hypotheses formulated after review of the first three cycles of CRSP research. Special attention was paid to the economic aspects of CRSP pond management procedures. Further, the Data Analysis and Synthesis Team (DAST) started to systematically use the Central Database.

The Fifth Work Plan was developed by the Technical Committee in May 1989, and encompassed research efforts carried out between 1 September 1989 and 31 August 1991. In addition to the Global Experiment, each site proposed various studies that addressed specific aquaculture needs of the host countries. Field experiments with farmer-cooperators were initiated, allowing researchers to evaluate their strategies under working conditions, and strengthening the linkage between research and practice. Economic analysis became another tool by which the CRSP measured the quality of its research achievements. The DASTs efforts focused on refining models and developing fertilizer guidelines.

The Sixth Work Plan, which began on 1 September 1991 and ended 31 August 1993, was approved at the Ninth CRSP Annual Meeting in May of 1991. A 20% funding increase allowed the CRSP to broaden its research scope. Nine supplemental projects were included in the Sixth Work Plan. One of these studies was a preliminary investigation of women's participation in fish culture activities in Rwanda. This study was used to attract a buy-in from USAIDs Women In Development program (WID) to perform more complete investigations on the role of gender in fish culture in Rwanda. Also, under the auspices of the Thailand team, research activities were re-initiated in the Philippines.

Under the Seventh Work Plan, the CRSP resumed its original investigation of pond dynamics in brackish water systems, a line of research that had been temporarily suspended when the CRSPs brackish water sites in Panama and the Philippines were lost in 1987. The Seventh Work Plan also introduced biotechnology, and its strong potential to aid aquaculture industries both domestically and abroad, as a new research focus. Experiments originally scheduled to be conducted in Rwanda were reassigned to different sites after the outbreak of civil war. It is a sign of the CRSPs resilience and the global nature of the program that the Africa team was able to regroup and develop a revised Seventh Work Plan whose experiments are currently conducted in Honduras and the United States. Furthermore, research on the influence of elevation on tilapia production originally conducted in Rwanda is now being continued in the Philippines.

The Interim Work Plan covered experiments that were conducted during the transition year (May 1995 through April 1996). This deviation from the usual biennial Work Plan format was a result of delays in the grant renewal process. The Interim Work Plan allowed the successful transition form the third grant, with its focus on production research, to the fourth grant, which emphasizes aquaculture research that addresses environmental effects and social and economic aspects in addition to production optimization.

II. Research Program Accomplishments

The research conducted during this reporting period and described in the Interim Work Plan allowed the successful transition from the third grant with its focus on production research to the fourth grant which emphasizes a new balanced approach to aquaculture research by giving environmental effects and social and economic aspects equal weight with production optimization. During this reporting period, researchers investigated the effects of pond management practices on water quality and—through effluents—on the larger environment. Researchers were also interested in the effects of the environment on efficacy and efficiency of aquacultural practices. Data analysis and modeling efforts moved along the same lines of inquiry. Models from the decision support system, POND©, proved valuable in a FAO effort to develop a geographic information system for Latin America. A fourth research theme during the past year was fish reproduction.

In addition to the traditional dissemination avenues, such as on-farm research, CRSP research results and raw data (via the Central Database) are now electronically available on the World Wide Web (WWW).

Research activities are presented under the following categories: Global Studies and Activities, Central America, East Africa, Southeast Asia, and United States: Data Analysis and Synthesis. In reports entitled "Printed as Submitted" editorial changes were limited to correction of spelling and grammar only.

Global Studies and Activities

The Global Experiment is the centerpiece of PD/A CRSP research. During the Interim Work Plan the Global Experiment focused on the effects of aquaculture on the environment. Little information is available on the effect of semi-intensive pond management strategies on the quality of pond effluents. Unconsumed feeds and excess fertilizer contribute nutrients to pond water and—when discharged—may deteriorate water quality in receiving waters. The development of nutrient budgets will permit researchers to quantify the potential pollution impact of a specific pond management strategy.

In Thailand, researchers investigated the effect of reduced fertilization on water quality. In treatment A, ponds were fertilized throughout the experimental period and commercial feed was added beginning on day 80, while ponds in treatment B were fertilized only until day 80 and then given commercial feed starting on day 80 until to the end of the experimental period. Fish growth performance was significantly better in treatment A than in treatment B; however, water quality parameters measured for each treatment were not significantly affected. In terms of nutrient budgets, estimated N and P budgets for both treatments revealed that fertilizer was the major nutrient input source. The total input of N and P was significantly higher for treatment A than B. The nutrient budgets also revealed that major portions of the total N and P inputs were not accounted for in the estimated losses. Unaccounted-for nitrogen may have been related to losses through denitrification processes in the pond sediments, and sedimentation may have been the primary mechanism for losses of phosphorus. Contrary to earlier studies indicating that pond muds serve as nutrient sinks, the results of this study show that large amounts of nitrogen and phosphorus were released from bottom soil to the water column during the culture cycle.

To assess the fate of nutrients added to brackish water systems, scientists from Auburn University, Alabama and the Laboratorio de Calidad de Agua, Honduras developed for nitrogen and phosphorus budgets of semi-intensively managed shrimp ponds receiving 20% protein (low) and 30% (high) protein feeds. Gross shrimp yield and final weights did not differ significantly between treatments, and no significant differences were detected between treatment water quality means. However, during the dry season, high protein feed resulted in significantly greater nitrogen and phosphorus additions to ponds. Inlet water was the source of all other nitrogen and phosphorus added to the ponds.

Researchers from the University of Hawaii and from Central Luzon State University, Philippines compared the growth performance of two strains of Nile tilapia: mixed-sex GIFT fish (Genetic Improvement of Farmed Tilapia) and GMT fish (Genetically Produced Male Tilapia). In the first treatment, inorganic fertilizers were applied weekly with an N:P ratio of 5:1 by weight. The second treatment utilized the same fertilization rate as treatment one, but only for the first 2.5 months of the experimental period. At this time commercial feed at 5% of body weight per day (BWD) was offered for the next 1.5 months, then feeding was at 3% BWD for the last month. Ponds were also stocked with African catfish (*Clarias gariepinus*) fingerlings as predatory control of tilapia reproduction. Fish of both strains of tilapia had significantly better yields and growth rates with the management regime that included feeding; however, yields were greater for the GMT fish. GMT fish also exhibited significantly better survival than GIFT fish under the management regime that did not include feeding.

In addition to the Global Experiment, CRSP scientists also collaborated in the following studies and activities which have worldwide significance: applications of the decision support system POND©, improved access to the entral Database, and socioeconomic research.

Data Analysis and Synthesis Team (DAST) members from Oregon State University (OSU) collaborated with scientists from the Food and Agriculture Organization (FAO) Inland Water Resources and Aquaculture Service. They estimated fish yield in Latin America as part of FAO's effort to assess aquaculture potential through the use of a geographical information system (GIS). The POND© heat balance model was used to generate water temperature profiles for continental Latin America. These profiles were then used in the POND© fish growth model together with pre-set satiation feeding levels and harvest sizes to estimate the maximum number of crops per year under commercial-scale aquaculture for four fish species: Nile tilapia *(Oreochromis niloticus)*, tambaquí *(Colossoma macropomum)*, pacu *(Piaractus mesopotamicus)*, and common carp *(Cyprinus carpio)*. The potential for small-scale and subsistence aquaculture was also evaluated. Results suggest that large areas of Latin America are suitable for commercial-scale aquaculture of all four species. Approximately 34% to 70% of the land area assessed was suitable for the culture of Nile tilapia and carp, respectively. Results of the simulations indicate that the integration of the POND© fish growth model with GIS is a useful tool to address the effects of various factors, primarily water temperature and feeding rate, on fish yields over large geographic regions, and to estimate production potential at various levels of culture intensity.

Other applications of POND© decision support software generated information for pond aquaculture planning and management. A water budget model that considers various sources (i.e., regulated inflow, precipitation, and runoff) and sinks (i.e., evaporation, seepage, effluent discharge, and overflow) was used to predict water requirements for CRSP sites in Thailand (AIT) and Honduras (El Carao) over a full growing season. The difference between actual and predicted amounts of regulated water inflow was 20.3 m^3 lower than the amount actually added for AIT and 141.3 m^3 for El Carao. More complete weather data sets for AIT may explain the higher accuracy in evaporative water loss estimates, which suggests that CRSP data collection protocols should be expanded to include measurements of cloud cover and relative humidity.

POND© was also used to revise fertilization guidelines originally developed through PONDCLASS. These revisions included the use of gross rather than net primary productivity to estimate nutrient requirements for algae, the consideration of nitrogen and phosphorus cycling in ponds, and the functional representation of the effects of nutrient concentrations and temperature on algal growth. Results of a model verification of the revised fertilization guidelines revealed that the revised guidelines were more conservative than PONDCLASS fertilization guidelines. This finding is consistent with fertilization strategy research indicating that strategies accounting for ambient pond water conditions are more likely to be superior in terms of cost and efficiency of fertilizer use compared with fixed input strategies.

Feed requirements for aquaculture ponds were also assessed through the use of the POND© bioenergetics (BE) model. A fixed feeding regime (100% satiation feeding protocol for Nile tilapia culture in fertilized ponds) was compared at three elevations. Results of the comparison suggest that this practice may be economically inefficient because it does not consider natural food consumption and variations in fish appetite due to seasonal water temperatures. Additional experiments using the BE model examined supplemental feed requirements for fertilized ponds stocked with Nile tilapia at two different densities (1 and 2 fish/m^2). Findings showed that feeding requirements would be about four to five times higher in ponds stocked at higher densities. Another experiment applied the BE model to generate information on feed requirements for unfertilized ponds located at three different elevations (MSL, 500 m, and 1000 m). Use of the BE model is advantageous when compared to feeding tables because the model is able to generate feeding curves that reflect the effects of fish size, as well as ambient water temperature and photoperiod, on appetite.

Simulations of plankton biomass changes in Nile tilapia ponds stocked at 1, 2, and 3 fish/m^2 were also undertaken using more complex POND© models. Although zooplankton biomass was similar for all three treatments, the biomass of phytoplankton pools differed substantially.

POND© heat balance and fish growth models also were used to conduct sensitivity analyses. Daily pond water temperatures predicted by the heat balance model were most sensitive to mean air temperature, followed by relative humidity, short-wave solar radiation, cloud cover, and wind speed. A comparison of ten parameters showed that the fish growth model is extremely sensitive to five anabolic and one catabolic parameters. Accuracy in parameters estimation is therefore of the great importance. Accurate estimations are achievable via a combination of field experimentation and appropriate use of the POND©.

Efforts such as the creation of a decision support system depend on a large amount of data for model generation and validation. The PD/A CRSP Central Database is the world's largest database containing standardized data on tropical aquaculture. The database—now housed at OSU—is managed using Microsoft Access and consists of only one computer file containing multiple data tables. A user and investigator interface to the Central Database is now available at the Internet: http://biosys.bre.orst.edu/crspDB/ with a link to the PD/A CRSP homepage and other aquaculture-related web sites. In addition, users will also be able to access a mirror site (currently under construction) at the web site of the Consortium of International Earth Science Network (CIESIN).

The production and marketing experiences of medium and small-scale family farms—a sector of the population whose well-being may be most immediately affected by the impacts of aquaculture—was the focus of a socioeconomic study. CRSP researchers from Auburn University interviewed tilapia farmers from Rwanda, Honduras, Thailand, and the Philippines. The results of this study provided information on production cycle characteristics, relative prices of fish, market constraints, and the problems associated with marketing tilapia. Production cycles were shortest in the Philippines, ranging from 139 to 149 days; Honduran production cycles ranged from 194 to 263 days; and Thailand farmers had the longest production cycle, which ranged from 307 to 358 days. The most frequently used harvest approach was pond draining at the end of the culture period. Final size of the fish, consumer size preference, and available market outlets influenced the price received for tilapia. Comparable prices were achieved in Honduras and the Philippines—prices ranged from $0.68 to $1.65 per kilogram of fish and $0.97 to $2.34 per kilogram of fish, respectively. However, in Thailand the price of fish was much lower, ranging from $0.12 to $0.99 per kilogram of fish. Production data were not obtained for Rwanda.

In terms of market participation, 60% of the Rwandan farmers did not sell any fish from their last harvest. Honduran respondents from small- and medium-sized farm categories kept higher percentages of their fish harvest for home consumption. Philippine farmers within the small-sized farm category did not sell their fish, and a portion was kept for home consumption, whereas owners of medium and large ponds sold their entire harvest. Thai farmers sold all their fish and did not keep any fish for home consumption.

Two thirds of all the farmers surveyed from Rwanda, Honduras, Thailand, and the Philippines stated that they had no problems marketing tilapia; however, Thailand farmers expressed concern that they were not receiving the price they desired for their product. Additionally, it was found that consumer fish size preference affected the marketing of tilapia. Three quarters of Rwandan farmers felt that large fish would be easier to sell; and almost all respondents from Thailand and the Philippines and half of the pond operators in Honduras felt that larger fish were optimal for marketing.

Grisela Suazo, administrator of the El Carao National Fish Culture Research Center in Honduras. El Carao has been a CRSP research site since 1983.

The Effects of Pond Management Strategies on Nutrient Budgets: Honduras

Interim Work Plan, Global Experiment, Honduras

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Introduction

Semi-intensive shrimp production in Honduras is based upon use of formulated diets to supply nutrients for shrimp growth. Unconsumed feed contributes nutrients to pond water, which when discharged may deteriorate water quality in receiving waters. Estuaries are the water source and sink for shrimp farms in Honduras, and many farms have been established along individual estuaries. A key element in achieving sustainable shrimp culture in Honduras is to ensure that the carrying capacity of each estuary is not exceeded because of overdevelopment of farms or uncontrolled intensification of production practices, both of which could result in significant increases in nutrient load entering estuaries due to farm discharges. Nutrient budgets are developed to assess the fate of nutrients added to a system and to rank importance of nutrient sources and sinks. In addition, the potential pollution impact of a specific pond management system could be evaluated using nutrient budgets. The objective of this experiment was to develop budgets for nitrogen and phosphorus in semi-intensively managed shrimp ponds receiving a low or high protein feed.

Materials and Methods

Eight ponds located on a commercial shrimp farm on a riverine estuary of the Gulf of Fonseca, Honduras, were used for this dry season study. Ponds were selected at random from a group of 12 ponds. Ponds averaged 1.67 ± 0.07 ha, 0.57 ± 0.06 m, and 9431 ± 993 m^3, in area, depth and volume, respectively. Two treatments (using different feed protein content) were tested applying a completely randomized design with four replicates per treatment.

Ponds were stocked with hatchery-produced, post-larval (PL) *Penaeus vannamei* (325,000/ha) on 19 January 1996. Stocking rate of PL shrimp was based on a historical Taura Syndrome survival rate of 25%, and was selected to achieve a final stocking rate of approximately 80,000 shrimp/ha; most Taura Syndrome mortality occurs within the first month following stocking. Ponds were harvested 87 days after stocking.

Feed protein levels tested were 20% and 30% crude protein; a commercial ration manufactured locally by ALCON was used. Shrimp were offered feed six days per week beginning on 13 February 1996. Feed rate for each treatment was 50% of the theoretical feeding curve for *P. vannamei*:

$$\text{Log}_{10}Y = -0.899 - 0.561\text{Log}_{10}X$$

where,

Y = feed rate as a % of biomass; and

X = mean weight of shrimp in grams.

Daily feed rate was calculated for individual ponds, and then averaged by treatment, so all ponds within a treatment received the same quantity of feed on a daily basis. Feed was provided once daily. Weekly cast net samples of each pond's population were taken to monitor shrimp growth; feed rate was adjusted weekly based on shrimp samples. Feed conversion ratio was calculated as the weight of feed provided divided by gross whole shrimp yield.

Losses to seepage and evaporation were replaced weekly. No water was exchanged during the first three weeks of culture. Water was exchanged at 20% of the pond volume once per week beginning on week four. If early morning dissolved oxygen concentration was ≤ 2.5 mg/l, 5% of the pond volume was exchanged. In all water exchanges, pond level was lowered first and then refilled. Dates and quantities of all water additions and exchanges were recorded.

Water budgets were estimated for each pond. All ponds were equipped with staff gauges. Regulated inflow water and discharge water volumes were estimated from changes in stage. Faulty equipment prevented direct measurement of evaporation; a combined estimate of evaporation and seepage was made from changes in stage on days no water addition or exchange occurred.

Pond water quality variables were measured upon initiation of the experiment, and beginning with the initiation of scheduled water exchange on week four, discharge and replacement water quality was monitored weekly. Weekly discharge water samples were collected from each pond's outfall during water exchange. Because all ponds were supplied from a common water supply canal, water samples for replacement water analysis were collected at each of the extremes and the middle segment of the canal supplying the ponds. At harvest, water samples were collected at 100%, 10%, and 0% of pond volume for analysis. Initial pond water and replacement water samples were obtained with a column sampler. Water samples were analyzed for nitrate-nitrogen by cadmium reduction (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), filterable reactive phosphate (Grasshoff et al., 1983), chlorophyll-*a* (Parsons et al., 1992), total alkalinity by titration to pH 4.5 endpoint, salinity, and BOD_2 at ambient temperature. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation (Grasshoff et al., 1983).

Pond sediment samples were collected using a core sampler (4.2-cm ID) following pond inundation and prior to pond draining. Five to six core samples were collected along a transect across the width of the pond. Samples were collected along three transects per pond: near the inlet, the center, and the outlet. The top 2.5 cm of each soil core was collected according to methodology described by Munsiri et al. (1995); all core samples along a transect were pooled for analysis. Soils were analyzed for total phosphorus (perchloric acid digestion; Olsen and Sommers, 1982) and total nitrogen using a Leco Carbon-Hydrogen-Nitrogen Analyzer.

Nutrient budgets were estimated for total nitrogen and total phosphorus. Nutrient content in pond discharge was calculated from weekly water quality analysis data and the volume of water discharged. It was impossible to collect samples of discharge water during unscheduled water exchanges; therefore, water quality analysis data from the date closest to the exchange was used to estimate quantities of nutrients discharged. Samples of feed were collected monthly for nutrient analysis according to methodology described by Jackson (1958). Nitrogen and phosphorus concentrations of shrimp were taken (Boyd and Teichert-Coddington, 1995).

Table 1. Production data (mean ± SD) from 1.67-ha semi-intensively managed earthen shrimp ponds where a 20% or 30% protein feed was tested. Post-larval shrimp were stocked to achieve a final stocking rate of approximately 80,000 shrimp/ha. Four replicate ponds were used per treatment.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
Gross Yield Whole Shrimp (kg/ha per 87 d)	412 ± 50	490 ± 99 NS
Average Final Weight (g/shrimp)	6.1 ± 0.3	5.7 ± 0.4 NS
Survival (%)	21.1 ± 0.0	31.0 ± 1.4 NS
Feed Conversion Ratio	1.0 ± 0.1	0.9 ± 0.1 NS

NS: Variable means did not differ significantly (P > 0.05) between treatments.

Table 2. Mean water budget for 1.67-ha earthen shrimp production ponds used to test a 20% or 30% protein feed.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
Initial Fill (m^3)	10020	8842
Water Exchanged (m^3)	32314	30972
Replacement Water (m^3)	38296	35804
Drain Volume (m^3)	9657	8669
Seepage and Evaporation (m^3)	6784	6521
Difference (added - discharged) (m^3)	-439	-1516
Mean Seepage and Evaporation (cm/d)	0.48	0.45

Data were analyzed by ANOVA (Haycock et al., 1992). Percent data were arcsine transformed prior to analysis. Differences were declared significant at alpha level 0.05.

Results

Gross shrimp yields and mean final weights did not differ significantly between treatments (Table 1). Taura Syndrome continued to affect shrimp survivals, with mean survivals of 21% and 31% observed in the 20% protein and 30% protein feed treatments, respectively. Feed conversion ratios (FCR) were close to one and did not differ significantly (Table 1). Feed application was suspended during a 4- to 6-day episode of chronic low dissolved oxygen that occurred in ponds during week nine. Mean daily feeding rate did not differ between treatments and averaged 8.2 and 8.1 kg/ha per day in the 20% and 30% protein feed treatments, respectively.

Water budgets were developed for ponds (Table 2). No significant differences between treatments were observed for any component of the water budget. More than three pond volumes of water were exchanged as part of the routine and emergency water exchange protocols. Mean estimated evaporation and seepage was 0.47 cm/d. No rainfall occurred during this study, which took place entirely during the dry season. Water outflow exceeded inflow.

Concentrations of water quality variables increased throughout the culture period (Figure 1). Total nitrogen and phosphorus, chlorophyll-*a*, and BOD_2 concentrations in inlet water were significantly lower than in pond water (Table 3). Nitrate was not detected in either the inlet water

Table 3. Mean concentrations (± SD) of water quality variables in 1.67-ha shrimp production ponds and in water supply canal. Shrimp in four replicate ponds each were offered a 20% or 30% protein feed.

Variable	Treatments		Water Supply Canal
	20% Protein Feed	*30% Protein Feed*	
Total Ammonia Nitrogen (mg/l)	0.022 ± 0.005 a	0.020 ± 0.008 a	0.017 ± 0.006 a
Total Nitrogen (mg/l)	1.77 ± 0.09 b	1.78 ± 0.13 b	0.69 ± 0.05 a
Soluble Reactive Phosphorus (mg/l)	0.10 ± 0.11 a	0.11 ± 0.05 a	0.05 ± 0.01 a
Total Phosphorus (mg/l)	0.25 ± 0.10 ab	0.32 ± 0.08 b	0.12 ± 0.01 a
Total Alkalinity (mg/l as $CaCO_3$)	154.6 ± 19.9 a	147.7 ± 5.2 a	-
Chlorophyll-*a* (mg/m^3)	54.96 ± 8.08 b	53.19 ± 13.41 b	24.21 ± 7.63 a
BOD_2 (mg/l)	9.84 ± 1.21 b	9.69 ± 1.32 b	5.52 ± 0.44 a

ab: Variable means followed by the same letter are not significantly different ($P < 0.05$).

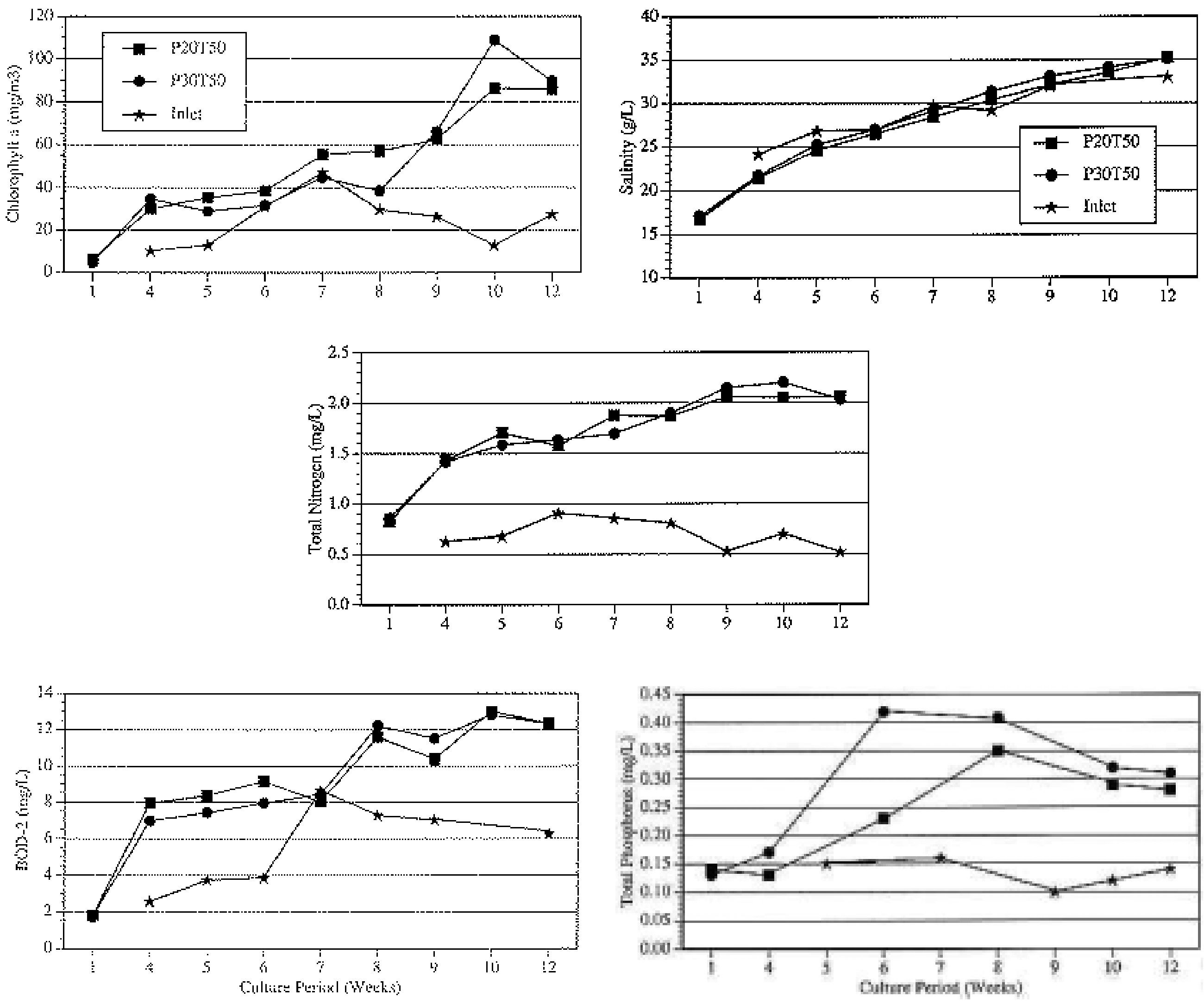

Figure 1. Mean weekly concentrations of 5 variables in ponds receiving a 20% protein (P20T50) or a 30% protein (P30T50) feed, and in inlet water.

or in pond water. No significant differences were detected between treatment water quality means (Table 3). However, inorganic nitrogen and phosphorus introduced to ponds in inlet water were converted to organic forms. Salinity in pond water and inlet water increased similarly during the experiment (Figure 1).

The shrimp biomass stocked into ponds was less than 0.5 kg and did not contribute any nitrogen or phosphorus to the pond, although at harvest a mean of 22.3 kg nitrogen and 2.4 kg phosphorus were removed as adult shrimp (Table 4). Significantly greater quantities of nitrogen and phosphorus were added to ponds as feed in the 30% protein feed treatment. The concentration of nitrogen in pond sediments increased significantly during the 87-day culture period, but sediment phosphorus concentrations were unchanged (Table 5). Nutrient budgets showed that a total of 57 to 66 kg nitrogen and 11 to 12 kg phosphorus were added to ponds and 101 kg nitrogen and 12 to 13 kg phosphorus were exported from ponds; export of nitrogen exceeded import of nitrogen by 35 to 44 kg, while export of phosphorus exceeded import of phosphorus by 0.26-0.46 kg (Table 6). Feed accounted for 41 and 52% of added nitrogen and 47 and 55% of added phosphorus in the 20% protein and 30% protein feed treatments, respectively. Inlet water, either from

Table 4. Mean (± SD) quantities per pond of shrimp stocked and harvested, and feed applied, and mean nutrient composition of feed and shrimp. Each treatment was replicated in four 1.67-ha earthen ponds.

Variable	Treatments		
	20% Protein Feed	*30% Protein Feed*	
POST-LARVAL SHRIMP			
Quantity Added (kg)	0.3	0.3	NS
Dry Matter (%)[1]	25.5	25.5	na
Nitrogen (% of dry weight)[1]	10.6	10.6	na
Phosphorus (% of dry weight)[1]	1.3	1.3	na
Nitrogen Added as Shrimp (kg)	0	0	NS
Phosphorus Added as Shrimp (kg)	0	0	NS
ADULT SHRIMP			
Quantity Harvested (kg)	699	788	NS
Dry Matter (%)[1]	26.5	26.5	na
Nitrogen (% of dry weight)[1]	11.3	11.3	na
Phosphorus (% of dry weight)[1]	1.2	1.2	na
Nitrogen Removed as Shrimp (kg)	20.9	23.6	NS
Phosphorus Removed as Shrimp (kg)	2.2	2.5	NS
FEED			
Quantity Added (kg)	674	672	NS
Dry Matter (%)	91.2	91.6	NS
Nitrogen (% of dry weight)	3.744	5.544	*
Phosphorus (% of dry weight)	0.908	1.107	*
Nitrogen Added as Feed (kg)	23.0	34.1	*
Phosphorus Added as Feed (kg)	5.6	6.6	*

[1] Source: Boyd and Teichert-Coddington (1995).
NS: Variable means did not differ significantly ($P > 0.05$) between treatments.
* Variable means differed significantly ($P < 0.05$) between treatments.
na: Comparison not appropriate.

the initial fill or from water exchanges and replacement, was the source of all other nitrogen and phosphorus added to ponds. Harvest of shrimp accounted for 36 to 37% of applied nitrogen and 19 to 20% of applied phosphorus.

Discussion

Shrimp yields and final weight were not affected by dietary quality, and were similar to reported dry-season shrimp yields and final weights in Honduras (Teichert-Coddington and Rodriguez, 1995a and 1995b; Teichert-Coddington et al., 1996b). Taura Syndrome is endemic in southern Honduras and observed shrimp survivals in this experiment were typical for animals exposed to Taura Syndrome (Lightner and Redman, 1994; Brock et al., 1995).

Water quality variables were not affected significantly by feed protein content, although nearly 50% more nitrogen was added to ponds in the 30% protein feed treatment. Observed concentrations of water quality variables were consistent with data reported from previous shrimp production trials in Honduras (Teichert-Coddington and Rodriguez, 1995a). Additions of feed nitrogen represented 41 to 52% of total nitrogen additions to ponds. Total feed added to

Table 5. Mean (± SD) total nitrogen and total phosphorus concentrations in initial and final soil samples from experimental ponds. Treatments using 20% and 30% protein feed were tested. The top 2.5 cm of pond sediment from core samples were taken for analysis. Samples were collected after pond flooding and prior to pond draining.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
TOTAL NITROGEN		
Initial Sample (%)	0.11 ± 0.001	0.13 ± 0.000
Final Sample (%)	0.21 ± 0.000 *	0.19 ± 0.000 *
TOTAL PHOSPHORUS		
Initial Sample (mg/kg)	1214.1 ± 111.6	1266.4 ± 62.6
Final Sample (mg/kg)	1204.4 ± 145.7	1254.2 ± 124.8

* Initial and final variable means within treatment were significantly different ($P < 0.05$).

Table 6. Mean gains, losses and unrecovered quantities (in kilograms) of nitrogen and phosphorus in 1.67-ha earthen shrimp production ponds where shrimp were offered a 20 or 30% protein formulated ration. Four replicate ponds were used for each treatment.

Variable	Treatments			
	20% Protein Feed		*30% Protein Feed*	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
GAINS				
Shrimp Stock	0	0	0	0
Canal Water				
Initial Flooding	8.12	1.45	7.60	1.14
Replacement Water	25.36	4.59	23.99	4.41
Feed	23.43	5.38	34.30	6.87
LOSSES				
Shrimp Harvest	20.90	2.20	23.60	2.50
Pond Water				
Exchange Discharge	62.21	9.17	59.87	10.09
Draining	18.16	0.31	17.45	0.29
UNRECOVERED	-44.36	-0.26	-35.03	-0.46

ponds did not differ between treatments because there was no response in shrimp growth to improved diet quality. Also, the total quantity of feed added to ponds was low, equivalent to 8.2 kg/ha per day, a quantity well below the 40 to 50 kg/ha per day, which results in low dissolved oxygen and deteriorated water quality (Boyd, 1989; 1990).

Total ammonia-nitrogen and soluble reactive phosphorus concentrations in ponds were low and did not differ significantly from concentrations in inlet water. However, total nitrogen and total phosphorus concentrations in ponds were significantly greater than in inlet water, although a significant difference between treatments was not observed. Greater than 98% of total nitrogen and 30 to 40% of total phosphorus were in the organic form, which was composed of plankton, bacteria, and particulate organic matter, as evidence by greater chlorophyll-*a* and BOD_2 concentrations observed in pond water. The impact of shrimp pond effluents on receiving waters would result from elevated organic nitrogen and phosphorus loads, and BOD.

Feed applied to ponds contributed 41 to 52% of total nitrogen and 47 to 55% of total phosphorus added to ponds. Significantly more nitrogen and phosphorus were added to ponds that received the 30% protein feed. Exchange water accounted for the remaining nitrogen and phosphorus added to ponds. In an earlier trial, Teichert-Coddington et al. (1996a) reported that addition of feed to shrimp ponds represents 40 and 54% of total nitrogen and phosphorus additions, respectively. In contrast, feed accounted for 88.3 to 92.3% and 74.5 to 95.9% of measured nitrogen and phosphorus input, respectively, in ponds with no water exchange (Boyd, 1985; Daniels and Boyd, 1989).

Harvest of shrimp accounted for 36 to 37% of added nitrogen and 19 to 20% of added phosphorus in this experiment, which was higher than the 16% of added nitrogen and 10% of added phosphorus reported by Teichert-Coddington et al. (1996a). This difference in nutrient removal due to shrimp harvest likely resulted from a total feed usage per hectare. Teichert-Coddington et al. (1996a) reported values of total feed usage per hectare which were approximately three times greater than in the present study. Harvest of fish from fed ponds accounted for 19.7 to 24.7% of nitrogen and 29.7 to 41.8% of phosphorus (Boyd, 1985; Daniels and Boyd, 1989). When data from this study were pooled with data from these other studies by Boyd (1985), Daniels and Boyd (1989), Teichert-Coddington et al. (1996a) and nitrogen or phosphorus removed in animals at harvest was regressed against FCR, a significant relationship was observed for nitrogen ($R_2 = 0.772$; $p < 0.05$), but not for phosphorus. Thus, careful management of feed application could result in less feed nitrogen ending up in the environment.

Pond water discharged during water exchange and draining contained 77.3 to 80.4 kg nitrogen and 9.5 to 10.4 kg phosphorus. Considerably more nitrogen was exported from ponds than was added, while import and export of phosphorus was closely balanced, showing a net export of 0.3 to 0.5 kg phosphorus. There are several possible explanations for the discrepancy between nitrogen and phosphorus imports and exports during unscheduled water exchanges: inlet and outlet water were not analyzed for nutrient content, rather the data from the most recent weekly water quality analysis were used. Use of weekly data could have resulted in an overestimation of nutrients discharged. Also, the water exchange protocol (drain first, then refill) may not have been adhered to during unscheduled exchanges to rectify acute low dissolved oxygen, which would result in an overestimation of nutrient discharge because the pond inlet is opposite from the pond outlet. Finally, it is possible that nitrogen fixation occurred in ponds, which would have resulted in nitrogen input being underestimated.

Anticipated Benefits

Results of this study improve our understanding of nutrient budgets in fed brackish water ponds. At low feed rates during the dry season, feed protein level did not affect shrimp yields but did result in significantly greater feed nitrogen input with the high protein feed. Careful management of feed application could reduce nitrogen discharge from ponds.

Acknowledgments

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Literature Cited

Boyd, C.E., 1985. Chemical budgets for channel catfish ponds. Transactions of the American Fisheries Society, 114:291-298.

Boyd, C.E., 1989. Water quality management and aeration in shrimp farming. Fisheries and Allied Aquacultures Departmental Series No. 2. Alabama Agricultural Experiment Station, Auburn University, AL, 83 pp.

Boyd, C.E., 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, AL, 482 pp.

Boyd, C.E. and D. Teichert-Coddington, 1995. Dry matter, ash, and elemental composition of pond-cultured *Penaeus vannamei* and *P. stylirostris*. Journal of the World Aquaculture Society, 26:88-92.

Brock, J.A., R. Gose, D.V. Lightner, and K. Hasson, 1995. An overview on Taura Syndrome, an important disease of farmed *Penaeus vannamei*. In: C.L. Browdy and J.S. Hopkins (Editors), Swimming Through Troubled Water. Proceedings of the Special Session on Shrimp Farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, LA, pp. 84-94.

Daniels, H.V. and C.E. Boyd, 1989. Chemical budgets for polyethylene-lined, brackishwater ponds. Journal of the World Aquaculture Society, 20:53-60.

Grasshoff, K., M. Ehrhardt, and K. Kremling, 1983. Methods of seawater analysis. Verlag Chemie,Weinheim, Germany, 419 pp.

Haycock, K., J. Roth, J. Gagnon, W.R. Finzer, and C. Soper, 1992. StatView 4.0 (software). Abacus Concepts, Inc., Berkeley, CA.

Jackson, M. L., 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, NJ, 498 pp.

Lightner, D.V., and R.M. Redman, 1994. Histopathology, histochemistry and ultrastructural studies of Taura Syndrome, a putative toxicity syndrome of penaeid shrimp (abstract). In: Book of Abstracts, World Aquaculture '94, 14-18 January, 1994, New Orleans, LA, World Aquaculture Society, Baton Rouge, p. 227.

Munsiri, P., C.E. Boyd, and B.F. Hajek, 1995. Physical and chemical characteristics of pond bottom soil profiles in ponds at Auburn, Alabama, USA, and a proposed system for describing pond soil horizons. Journal of the World Aquaculture Society, 26:346-377.

Olsen, S.R., and L.E. Sommers, 1982. Phosphorus. In: A.L. Page (Editor), Methods of Soil Analysis, Part 2, Agronomy 9. American Society of Agronomy, Inc., Soil Science Society of America, Inc., Madison, WI, pp. 403-430.

Parsons, T.R., Y. Maita, and C.M. Lalli, 1992. A manual of chemical and biological methods for seawater analysis. Pergamon Press, New York, 144 pp.

Teichert-Coddington, D.R., and R. Rodriguez, 1995a. Inorganic fertilization and feed reduction in commercial production of *Penaeus vannamei* during wet and dry seasons in Honduras. In: H. Egna, J. Bowman, B. Goetze and N. Weidner (Editors), Twelfth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 136-146.

Teichert-Coddington, D.R. and R. Rodriguez, 1995b. Semi-intensive commercial grow-out of *Penaeus vannamei* fed diets containing differing levels of crude protein during wet and dry seasons in Honduras. Journal of the World Aquaculture Society, 26:72-79.

Teichert-Coddington, D.R., D. Martinez, and E. Ramirez, 1996a. Characterization of shrimp farm effluents in Honduras and chemical budget of selected nutrients. In: H. Egna, B. Goetze, D. Burke, M. McNamara and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development Oregon State University, Corvallis, Oregon, USA, pp. 70-84.

Teichert-Coddington, D.R., W. Toyufuku, J. Harvin, and R. Rodriguez, 1996b. Relationships among stocking density, survival, and yield in ponds affected by the Taura Syndrome during wet and dry seasons in Honduras. In: H. Egna, B. Goetze, D. Burke, M. McNamara and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development Oregon State University, Corvallis, Oregon, USA, pp. 85-94.

The Effects of Pond Management Strategies on Nutrient Budgets: Thailand

Interim Work Plan, Global Experiment, Thailand

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Introduction

The PD/A CRSP pond experiments have involved a variety of pond input schemes for fish production, including fertilizers, formulated feed, and a combination of both. With high fertilization rate, the nutrients assimilated in fish biomass were estimated to be less than 20% for nitrogen and 10% for phosphorus (Edwards, 1992). Most of those lost nutrients are distributed in water, fish biomass, and sediments of the pond systems. It is generally believed that a large proportion of nutrients received in ponds ends up in pond muds and discharged effluents. To reduce the nutrient losses in discharged water, it is essential to estimate the nutrient budgets to assess the fate of nutrients added to the pond culture systems. Development of nutrient budgets would permit quantification of potential pollution impact of a specific pond management strategy. The objective of this experiment was to compare nitrogen and phosphorus budgets in ponds with different fertilization and feeding schemes.

Materials and Methods

The experiment was conducted in six 280-m^2 earthen ponds at Bang Sai station in Ayutthaya Province, Thailand. Two experimental treatments, each conducted in triplicate, were: (A) Ponds were fertilized throughout the experimental period and commercial feed (30% crude protein) was added beginning day 80; and (B) Ponds were fertilized until day 80 and followed by commercial feed (30% crude protein) only. Sex-reversed, all male Nile tilapia with an average weight of 23-24 g were stocked at 3 fish/m^2 (840 per pond) on 16 November 1995. All ponds were fertilized weekly with urea (1.7 kg/pond/week) and TSP (1.0 kg/pond/week) to make a 4:1 N/P ratio. Feeding commenced in both treatments on day 80 of the culture period. Feeding rate was adjusted weekly for each pond according to the total amount of feed consumed during one hour in the morning (1000-1100 h) and afternoon (1400-1500 h) on the first day of each week. The average amount of feed consumed in each treatment was used as daily ration for the treatment over the remainder of the week. The water depth of each pond was maintained at 1 m by topping off weekly to replace losses to seepage and evaporation.

Fish growth was measured every two weeks by sampling 40 fish from each pond. Individual weight and length were taken. The chemical and physical conditions of pond water were also monitored according to standard CRSP protocols stated in the Work Plan. Fish were harvested on 25 April 1996, after 160 days of culture.

The nutrient budgets for N and P in ponds during the experimental period were calculated based on inputs from water, stocked fish, fertilizer and feed, losses in fish harvest, discharge water, and sediment. Sediment samples were collected from the top 5 cm of each pond bottom following initial pond bond filling and immediately before fish harvest and were analyzed for total nitrogen, total phosphorus, moisture, and bulk density. Total nitrogen and phosphorus content were analyzed for commercial fish feed and for fish sampled at stocking and harvest.

Data were presented for each treatment in weight and percentage of the nutrient derived from the total inputs and losses. One way analysis of variance was used to sort out the effect of treatment on water quality, fish growth, production, nutrient content in discharge water, and total output of nutrient. Differences were considered significant at an alpha level of 0.05.

Results and Discussion

Water Quality

Among pond water quality parameters measured (Table 1), DO values of both treatments were most variable ranging from 1.0-10.6 mg/l with occasional drops below 0.5 mg/l towards the end of the culture cycle (Figure 1). The mean total alkalinity value in treatment A and B was 104.3 ± 21.7 and 88.4 ± 2.4 mg/l $CaCO_3$, respectively. The highest value was observed in the first week, and values for total alkalinity declined toward the end of culture period (Figure 2). Mean TAN concentration in both treatment A and B was 0.72 ± 0.31 and 0.24 ± 0.03 respectively (Figure 3). Mean chlorophyll-*a* concentration in treatment A and B was 139.7 ± 36.2 and 110.8 ± 15.5 µg/l, respectively, and it showed a relatively stable concentration in all ponds towards the later half of the culture period (Figure 4). Total Kjeldahl nitrogen and total phosphorus concentrations in treatment A and B followed a similar trend up to

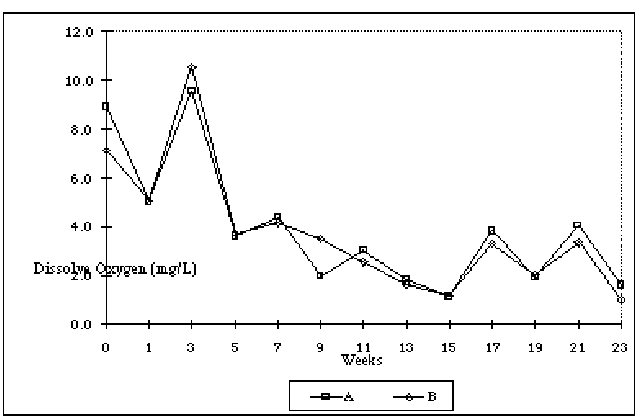

Figure 1. Fluctuation of dissolved oxygen (mg/l) in both treatments over the culture period.

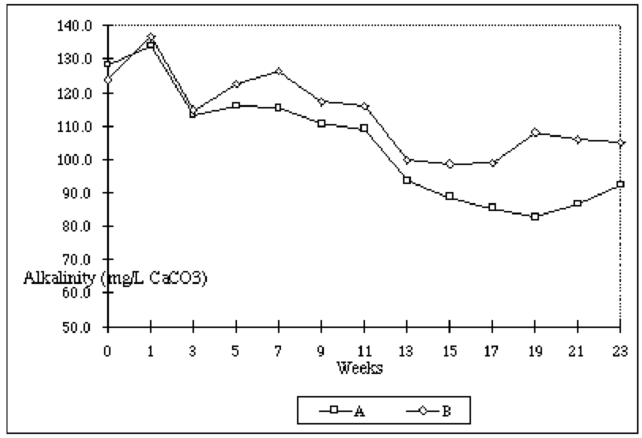

Figure 2. Fluctuation of alkalinity (mg/l $CaCO_3$) in both treatments over the culture period.

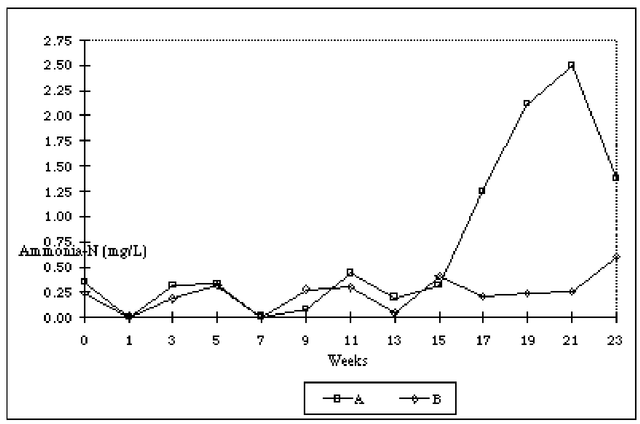

Figure 3. Fluctuation of total ammonia nitrogen (mg/)in both treatments over the culture period.

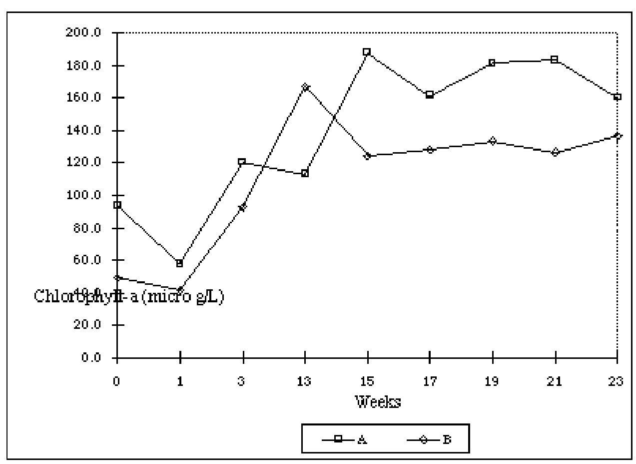

Figure 4. Fluctuation of Chlorophyll-*a* (µg/l) in both treatments over the culture period.

Table 1. Mean values of water quality parameters in treatment A and B over the culture period.

Variable	Treatment A	Treatment B
DO (mg/l)	3.5 ± 0.3	3.5 ± 0.2
Temperature (°C)	27.4	27.4
pH (range)	7.0-8.7	7.4-8.6
Alkalinity (mg/l)	104.3 ± 21.7	88.4 ± 2.4
TKN (mg/l)	5.6 ± 0.3	4.4 ± 0.2
TAN (mg/l)	0.72 ± 0.31	0.24 ± 0.03
NO_2- N (mg/l)	0.13 ± 0.02	0.06 ± 0.02
TP (mg/l)	0.57 ± 0.09	0.50 ± 0.06
SRP (mg/l)	0.07 ± 0.03	0.07 ± 0.02
Chlorophyll-*a* (µg/l)	139.7 ± 36.2	110.8 ± 15.5
TSS (mg/l)	151.2 ± 19.1	154.4 ± 20.2
TVS (mg/l)	45.2 ± 11.1	41.8 ± 2.3
Secchi Disk Visibility (cm.)	14.1 ± 1.2	12.8 ± 1.5

Values are mean ± S.E. (n= 3 for each treatment). For each pond water quality data for all sampling times were averaged.

week 13, but with the commencement of feeding, higher N and P levels were observed in treatment A than in treatment B (Figures 5 and 6). Statistical analysis showed that there were no significant difference for TAN, TP and chlorophyll-*a* concentrations between the treatments ($P > 0.05$). The results of this experiment show that different pond inputs in treatment A and B did not significantly affect major water quality parameters.

Fish Production

Fish growth performance in treatment A was significantly better than that of treatment B ($p < 0.05$) (Table 2). The final maximum mean weight was 314 g with a total yield of 227.8 ± 4.4 kg per pond in treatment A, compared to 248 g/fish and total yield of 182.4 ± 16.9 kg per pond in treatment B.

Daily weight gain in both treatments was similar up to day 80, but the final yield was greater in the treatment with continuous fertilization plus feeding than the treatment with feed input alone. The low feed conversion ratio (0.83-1.28) in this study confirms that the fish growth benefited from natural diet stimulated by fertilization. Green (1992) reported that fish production at El Carao, Honduras was 5305 kg/ha in 150 d, and the feed conversion was 1.8 when feed (24% protein) was the only input offered to tilapia stocked at 2 fish/m². However, he

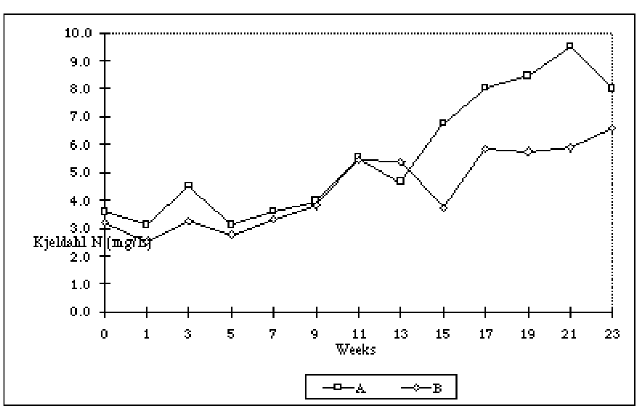

Figure 5. Fluctuation of total Kjeldahl nitrogen in both treatments over the culture period.

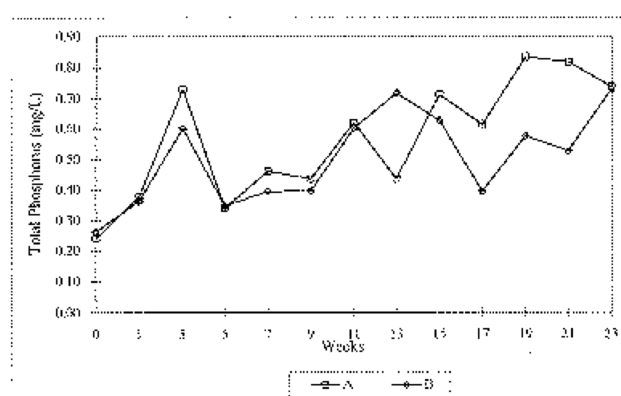

Figure 6. Fluctuation of total phosphorus (mg/l) in both treatments over the culture period.

observed that the natural productivity stimulated by pond fertilization was sufficient to permit rapid fish growth during the first two months of culture.

Nutrient Budget

The estimated N and P budgets in both treatments showed that fertilizer was the major source of nutrient inputs and the second was commercial feed (Table 3). The total input of N and P was significantly higher in treatment A than in treatment B ($p < 0.05$), and the amounts of N and P input from water, fish, fertilizer, and feed for both treatments are compared in Figures 7 and 8.

Nitrogen and phosphorus losses in various components of the pond system are shown in Figures 9 and 10. Fish harvest removed 15.45-20.04% N and 10.02-15.10% P from the total inputs and there was no significant difference between treatments ($p > 0.05$). Losses of N and P in discharged water at harvest ranged from 7.19-10.81% and 2.00-3.84% of the total inputs, respectively, and the nutrient content in effluent water at harvest was not significantly different between treatments ($p > 0.05$).

The nutrient budget showed that major portions of the total N and P inputs to the ponds were not accounted for in the estimated losses. The unaccounted loss of N and P for all ponds ranged between 70.66-78.01% and 81.88-87.25% of the total inputs, respectively. Chien et al. (1989) mentioned that sediment plays an important role in the balance of an aquaculture system; it can act as a buffer in water nutrient concentration. Avnimelech et al. (1984) emphasized that the sediment layer of few centimeter depth contains more nutrients than the content of the water column. The large amount of unaccounted for nitrogen was probably related to losses through

Table 2. Inputs and fish growth performance in treatment A and B for tilapia cultured for 16 weeks.

Variable	Treatment A	Treatment B
STOCKING		
Density (fish/m^2)	3	3
Total No.	840	840
Mean Weight (g)	23 ± 0.5	24 ± 0.2
Total Weight (kg/pond)	19.6 ± 0.3	20.3 ± 0.2
HARVEST		
Total No.	731 ± 11	733 ± 17
Survival	87.0 ± 1.3	87.3 ± 2.0
Mean Weight (g)	312 ± 1.8	248 ± 17.5
Total Weight (kg/pond)	227.8 ± 4.4	182.4 ± 16.9
Weight Gain (kg/pond)	208.2 ± 4.5	162.1 ± 17.0
DWG (g/fish/day)	1.78 ± 0.0	1.38 ± 0.1
Net Yield (t/ha/year)	16.7 ± 0.4	13.0 ± 1.4
FCR	0.87 ± 0.05	1.10 ± 0.1
INPUTS		
Feed (kg/pond)	182.1 ± 8.8	174.7 ± 5.9
UREA (kg/pond)	39.1 ± 0.0	20.4 ± 0.0
TSP (kg/pond)	23.0 ± 0.0	12.0 ± 0.0
REPRODUCTION		
Total No.	211 ± 140	458 ± 218
Mean Weight (g)	68.0 ± 20.0	47.0 ± 21.0
Total Weight (kg/pond)	11.2 ± 6.0	16.4 ± 7.0

Table 3. Comparison of nutrient budgets for N and P between treatment A and B over the culture period of 16 weeks.

	Treatments							
	A				*B*			
	Nitrogen (kg)	*%*	*Phosphorus (kg)*	*%*	*Nitrogen (kg)*	*%*	*Phosphorus (kg)*	*%*
Inputs								
Water	1.30 ± 0.08	4.62 ± 0.23	0.08 ± 0.01	1.16 ± 0.17	1.22 ± 0.05	6.36 ± 0.26	0.09 ± 0.02	1.89 ± 0.40
Fish	0.43 ± 0.01	1.53 ± 0.05	0.16 ± 0.01	2.37 ± 0.11	0.46 ± 0.01	2.42 ± 0.09	0.17 ± 0.00	3.79 ± 0.09
Fertilizer	17.99 ± 0.00	63.98 ± 1.07	4.60 ± 0.00	67.22 ± 0.88	9.38 ± 0.00	49.07 ± 0.67	2.40 ± 0.00	52.38 ± 0.70
Feed	8.41 ± 0.41	29.86 ± 0.93	2.00 ± 0.10	29.25 ± 1.02	8.07 ± 0.27	42.15 ± 0.84	1.92 ± 0.06	41.94 ± 0.87
Total	28.13 ± 0.48	100	6.85 ± 0.09	100	19.13 ± 0.26	100	4.58 ± 0.06	100
Losses								
Water	2.29 ± 0.16	8.12 ± 0.47	0.18 ± 0.12	2.58 ± 0.30	1.82 ± 0.11	9.53 ± 0.68	0.15 ± 0.01	3.32 ± 0.29
Fish	4.43 ± 0.19	15.75 ± 0.65	0.90 ± 0.11	13.14 ± 1.58	3.59 ± 0.23	18.79 ± 0.99	0.61 ± 0.03	13.33 ± 0.67
Total	6.72 ± 0.34	23.87 ± 1.07	1.08 ± 0.11	15.72 ± 1.53	5.41 ± 0.13	28.32 ± 0.53	0.76 ± 0.03	16.65 ± 0.87
Unaccounted	21.41 ± 0.42	76.13 ± 1.07	5.77 ± 0.19	84.28 ± 1.58	13.71 ± 0.21	71.68 ± 0.53	3.82 ± 0.09	83.35 ± 0.87
Nutrient Released by Soil	9.95 ± 0.80	35.49 ± 3.39	0.32 ± 0.80	16.96 ± 0.38	6.68 ± 1.45	34.72 ± 7.08	0.58 ± 1.38	33.40 ± 19.61

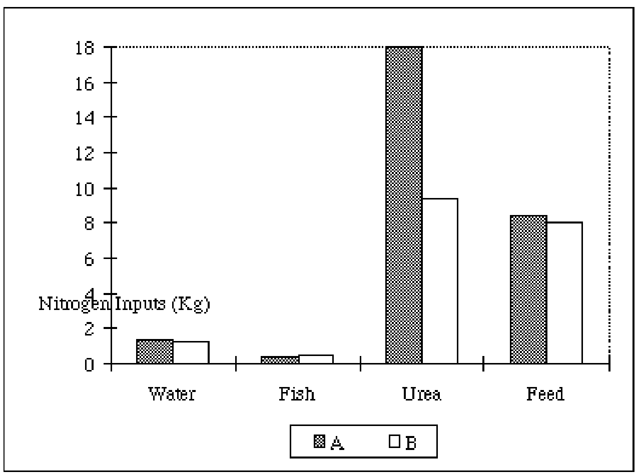

Figure 7. Comparison of nitrogen inputs (kg) in both treatments over the culture period.

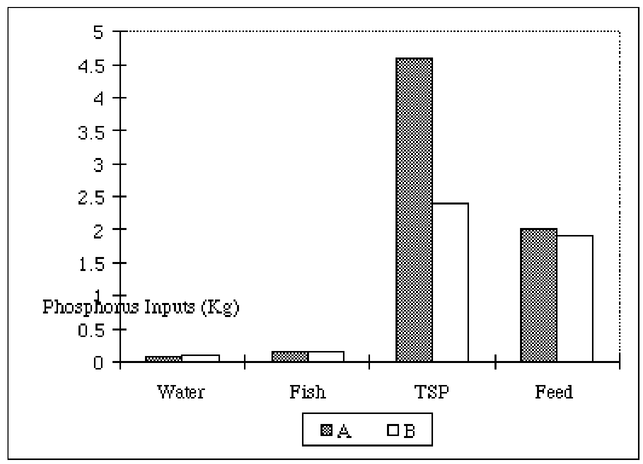

Figure 8. Comparison of phosphorus inputs (kg) in both treatments over the culture period.

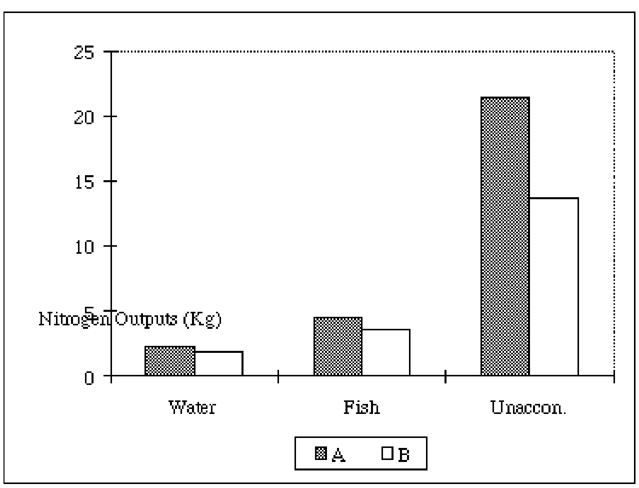

Figure 9. Comparison of nitrogen losses (kg) in both treatments over the culture period.

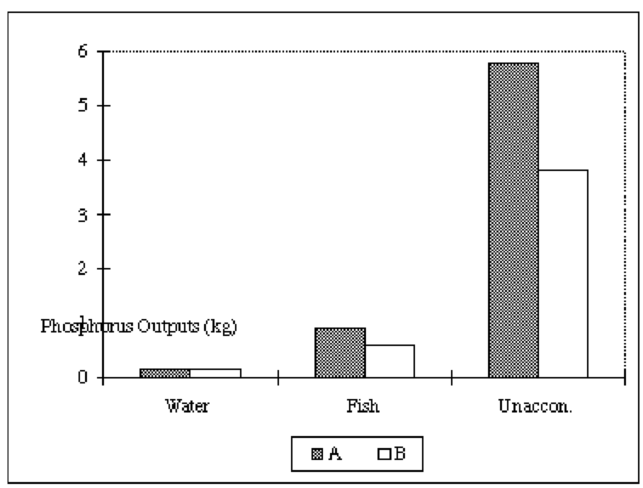

Figure 10. Comparison of phosphorus losses (kg) in both treatments over the culture period.

denitrification process in the sediment. Diab and Shilo (1986) reported that when ponds were refilled, anaerobic conditions developed beneath the soil surface, and nitrate was converted to nitrogen gas by denitrification. Sedimentation is generally considered a main mechanism for P loss in ponds because muds are known to have a strong affinity for phosphorus (Shrestha and Lin, 1996). Boyd (1985) explained that the amount of unaccounted for phosphorus would be analytically undetectable when incorporated in muds. Contrary to many earlier observations that pond muds served as nutrient sinks, the results of the present study show that large amounts of nitrogen and phosphorus (23.68-47.51% N and 0.34-31.68% P of the total inputs) were released from bottom soil to the water column during the culture cycle. This reverse occurrence might have resulted from large amounts of nutrient deposits in the muds from previous feeding experiments. This nutrient release from muds would be a significant source of nutrient to phytoplankton growth.

Acknowledgment

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Literature Cited

Avnimelech, Y., J.R. McHenery, and D.J. Ross, 1984. Decomposition of organic matter in lake sediments. Environmental Science and Technology, 18(1):5-11.

Boyd, C.E., 1985. Chemical budgets for channel catfish ponds. Trans. Am. Fish. Soc., 114:291-298.

Chien, Y.H., and H.T. Lai, 1988. The effect of aged sediments and stocking density on freshwater prawn *Macrobrachium rosenbergii* culture. J. World Aquaculture Soc., 19(1):22A-23A.

Diab, S. and M. Shilo, 1986. Transformations of nitrogen in sediments of fish ponds in Israel. Bamidgeh, 38:67-88.

Edwards, P., 1993. Environmental issues in integrated agriculture-aquaculture and waste water-fed fish culture systems. In: R.S.V. Pullin (Editor), Environment and Aquaculture in Developing Countries. ICLARM Conf. Proc., Vol. 31, pp. 139-170.

Green, B.W., D.R. Teichert-Coddington, and T.R. Hanson, 1994. Development of semi-intensive aquaculture technologies in Honduras: Summary of freshwater aquacultural research conducted from 1983 to 1992, Auburn University, International Center for Aquaculture and Aquatic Environments Research and Development Series No. 39, 47 pp.

Shrestha, M.K., and C.K. Lin, 1996. Phosphorus fertilization strategy in fish ponds based on sediment phosphorus saturation level. Aquaculture, 142:207-219.

The Effects of Pond Management Strategies on Nutrient Budgets: A Comparison of Mono-sex Swansea GMT and Mixed-sex GIFT Nile Tilapia (*Oreochromis niloticus*)

Interim Work Plan, Study 2 and Global Experiment, Philippines

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Introduction

PD/A CRSP pond management strategies have primarily used fertilizers to increase pond productivity. However, as countries develop, there is often a desire for larger fish, which are more difficult to produce in a short time if feeds are not used. This experiment aimed to contribute to PD/A CRSP information on the relative importance of various nutrient sources and to continue studies of the relative growth responses of different strains of *Oreochromis niloticus* under heavy fertilization and feeding regimes.

Materials and Methods

Four treatments compared the growth performance of two strains of Nile tilapia under two pond management regimes in a 2 x 2 factorial design. Each of the four treatments was represented by triplicate ponds, requiring use of 12 ponds in all. The strains were 1) mixed sex GIFT fish (Pullin et al., 1991) and 2) Swansea GMT fish (Capili, 1995). GIFT fish are *O. niloticus* that have been selectively bred by ICLARM (International Center for Living Aquatic Resources Management) and are typically cultured in mixed-sex groups. Swansea GMT fish are *O. niloticus* males produced by breeding YY male tilapia with normal females. All ponds were stocked with tilapia fingerlings of 4-7 g/fish individual weight at a density of 3 fish/m^2; all ponds were also stocked with fingerling African catfish (*Clarias gariepinus*), of weights ranging from 2.2 to 3.1 g/fish at 0.3 fish/m^2, for predatory control of tilapia reproduction.

The pond management regimes consisted of 1) weekly fertilization with urea and 16-20-0 organic fertilizer at a rate of 4 kg N/ha/day with an N:P ratio of 5:1 by weight; and 2) fertilization at the above rate through the first 2.5 months, followed by discontinuation of fertilizer inputs and initiation of feeding twice daily with commercial feed (27% protein content) at 5% body weight per day (BWD) for the next 1.5 months, and then feeding at 3% BWD for the last 1.0 month.

Water depth was measured and adjusted weekly to 0.9 to 1.0 m. Column-integrated water samples were taken between 0600 and 0900 hours once every two weeks for analysis of concentrations of total ammonia, soluble reactive phosphorus, and total alkalinity (APHA, 1989). As well, Secchi depth, and top, middle, and bottom (25, 50, 75 cm) depth determinations of dissolved oxygen concentration (DO, by polarographic probe in situ), in situ temperature, and pH of samples

Table 1. Summary of extrapolated harvest data (kg/ha/yr).

Oreochromis niloticus **Strain & Nutrient Input**	**Replicate**	**Stocked Tilapia Only**	**Total Yield***
GMT w/ Fertilizer	1	5420	6534
	2	6661	9122
	3	5621	7235
	Mean ± s.e.	5900 ± 385	7630 ± 773
GMT w/ Fertilizer then Feed	1	10928	15527
	2	9512	11953
	3	8659	14041
	Mean ± s.e.	9700 ± 662	13840 ± 1037
GIFT w/ Fertilizer	1	4726	7436
	2	5124	8353
	3	5078	8316
	Mean ± s.e.	4976 ± 126	8035 ± 300
GIFT w/ Fertilizer then Feed	1	7356	12931
	2	6437	12644
	3	6705	9309
	Mean ± s.e.	6833 ± 273	11628 ± 1162

* Includes tilapia catfish and reproduction.

returned to the laboratory (by combination electrode) were measured. The 3-depth samples were repeated the same afternoons between 1330 and 1600 hours.

Fish were sampled monthly for measurements of individual length and bulk weight—a sample of 25 fish taken without pattern from a seine haul. Fed ponds were sampled twice monthly so that rations could be adjusted for growth. Ponds were harvested by seining and complete draining after 150 days. Statistical comparisons were made.

Results

When fish of either strain were fed, growth and yield were significantly greater than in comparable unfed treatments. Yields of the stocked tilapia were greater for GMT than for GIFT fish in the fed treatment and in the fertilizer-only treatment (Table 1). Average weight of individual fish (pond means) did not differ significantly between strains in either feed regime, which implies that yield differences were mediated through survival differences. Survival was generally good (81-97% by pond), and in general better than was typical for earlier trials with other strains on this site, with the exception of one of 12 ponds with a low survival rate of 58%. GMT fish exhibited significantly better survival than GIFT fish in the unfed treatments; differences were smaller in the fed treatments, and non-significant if the single low value noted above is ignored.

Tilapia reproduction and catfish contributed significantly to total fish yields (Table 1). Catfish yields showed no significant difference when stocked with either tilapia strain, either by absolute amount or as percent of total pond yield.

Catfish yields were significantly greater in fed ponds, constituting 14.0 to 27.8% of total crop, compared with 10.5 to 14.3% in unfed ponds. All of these percentages exceeded the proportion in which catfish were stocked by numbers (10%) and biomass (5%).

In unfed ponds, GIFT fish produced significantly greater yields from reproduction than did GMT fish, as expected given that GIFT fish were not sex-reversed. This result was expected and complicated the comparison of the strains, but GIFT fish are usually not available as sex-reversed fingerlings. Within the fed ponds, the species comparison was further complicated by the presence of a few large offspring fish in some ponds.

Literature Cited

APHA (American Public Health Association), 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition. American Public Health Association, Washington, D.C.

Capili, B., 1995. Growth and Sex Determination in the Nile Tilapia, *Oreochromis niloticus* (L.). Ph.D. thesis, University of Wales Swansea.

Pullin, R.S.V., A.E. Eknath, T. Gjedrem, M. Tayamen, J. Macaranas, and T. Abella, 1991. The genetic improvement of farmed tilapias (GIFT) project: the story so far. NAGA: The ICLARM Quarterly, 14(2):3-6.

Applications of Heat Balance and Fish Growth Models for Continental-Scale Assessment of Aquaculture Potential in Latin America

Interim Work Plan, DAST Study 3

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Introduction

Strategic assessments of pond aquaculture potential require estimates of fish yields that are possible at different geographical locations. In a previous study that assessed the potential for warmwater aquaculture in Africa (Kapetsky, 1994), fish yields (expressed as the number of crops per year or crops/y) were estimated on the basis of temperature thresholds established for the model species (Nile tilapia, *Oreochromis niloticus*). However, this approach is not readily extended to other species of potential interest. Moreover, the approach does not directly consider the effects of seasonal water temperature variation on fish growth and food consumption rates, nor does it account for the effects of other factors (e.g., feeding levels, photoperiod, and fish size) on these rates. Bolte et al. (1995) have developed a fish growth model that accounts for the effects of temperature, photoperiod, size, and feeding level on fish weight. Techniques have also been developed to parameterize this model for different fish species (Bolte and Nath, 1996).

Water temperature is an important input variable required for assessment of fish yields. Kapetsky (1994) estimated the mean monthly water temperature for African ponds on the basis of a linear regression relationship between this variable and the mean monthly daytime air temperature. An alternative approach of predicting water temperature involves the use of heat balance models (e.g., Fritz et al., 1980). Such models account for the effects of geographical variations in air temperature, and in other weather characteristics (i.e., solar radiation, cloud cover, wind speed, and relative humidity) on pond water temperature. Nath (1996) developed and validated a heat balance model for use in pond aquaculture. The heat balance and growth models cited above have been packaged in the decision support system POND© (Bolte et al., 1995; Nath et al., 1995), which runs under the Microsoft Windows operating system.

This report focuses on the adaptation and application of these two models to estimate fish yields for four species across continental Latin America, as part of an FAO effort to assess pond aquaculture potential in the inland regions of Latin America. This report focuses primarily on the output generated by the fish growth model. Integration of these results with the rest of the GIS procedures, and a complete discussion of the potential for aquaculture in Latin America are presented elsewhere (Kapetsky and Nath, in prep.).

The fish species chosen for analysis were Nile tilapia (*O. niloticus*), tambaquí (*Colossoma macropomum*), pacu (*Piaractus mesopotamicus*), and common carp (*Cyprinus carpio*). Of these species, Nile tilapia culture is increasing in the warmer waters of Latin America because Nile tilapia are easy to culture, have rapid growth rates, and can tolerate a wide range of water quality conditions. Currently, carp is not widely cultured in Latin America; however, this species tolerates a wide range of temperatures and has a high potential for culture. The characids (tambaquí and pacu) are commercially cultured in several countries (e.g., Brazil, Colombia, and Venezuela) and are good candidates for pond aquaculture (Saint-Paul, 1989; Lovshin, 1995). Tambaquí generally perform well in warm waters (exceeding approximately 20°C), whereas pacu tolerate colder temperatures.

Methods

FAO's general framework for the continental-scale assessment of pond aquaculture potential in Latin America involves the use of a geographical information system (GIS), for which data were taken from direct sources or were generated by the use of one or more models. The GIS software used for the overall analysis at FAO is ARC/INFO, which runs under the UNIX operating environment. In order to predict water temperature and fish yields, it was necessary to modify the POND© heat balance and fish growth models so that the output information could be displayed within ARC/INFO. This was accomplished by implementing the two models as 'free-standing' applications (i.e., independent of the POND© software). Further minor modifications to the models and simulation settings are described below.

Water Temperature Modeling

The water temperature model is fully documented elsewhere (Nath, 1996). Validation of this model has been completed for different geographical locations using daily weather and site-specific input data recorded in the PD/A CRSP Central Database (Nath, 1996).

However, daily weather data required for the water temperature model are not easily available or accessible for large geographical regions such as Latin America. Moreover, manipulating and storing daily weather data for such a large grid are non-trivial tasks. Even if capabilities for such operations existed, it is unlikely that their use would result in significant advantages to strategic planning applications, such as continental-scale analysis of aquaculture potential.

The alternative approach taken in this study was to procure gridded data sets of the monthly values of air temperatures required for the water temperature model developed by the FAO Agrometeorology Group. Unfortunately, due to problems encountered by this group during interpolations of recorded weather data, gridded data sets of the other weather variables required as input to the water temperature datasets were not available. Air temperature data were interpolated to obtain daily values for use in the water temperature model; other input variables were predicted by the use of a simple weather generator described by Nath (1996). The analysis assumed that all the simulated ponds have a

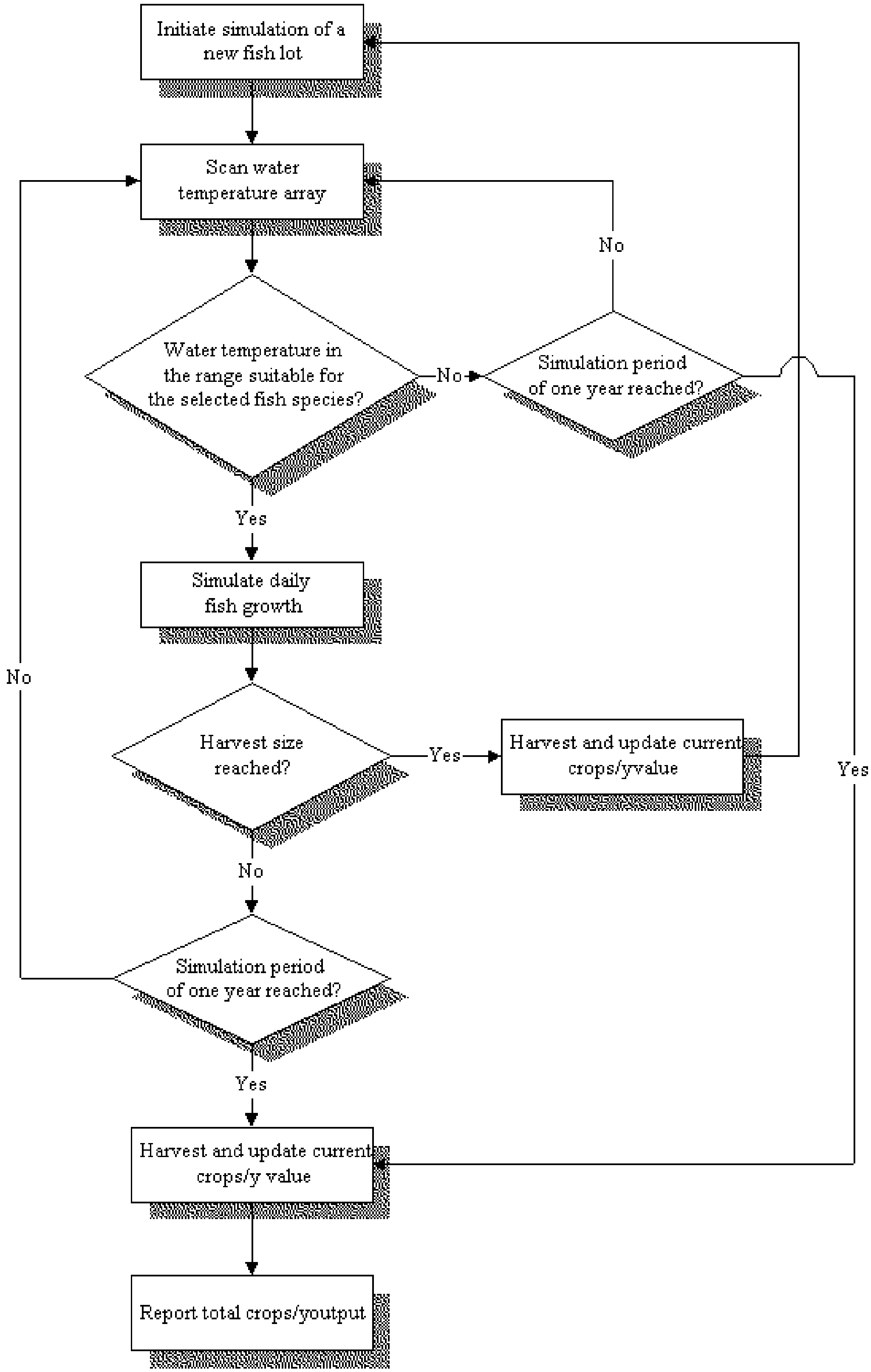

Figure 1. Flow diagram depicting the procedure used to calculate crops/y output using the simulation model of fish growth.

Table 1. Stocking densities and harvest sizes (small and large) assumed within each of the commercial farming scenarios for tilapia, tambaquí, pacu, and carp. Expected gross and net yields (after accounting for mortality) of a hypothetical output of one crop/y are also shown.

Species	Stocking Density (fish m^{-2})	Harvest Size (g)	Gross Yield (kg ha^{-1} yr^{-1})	Net Yield (kg ha^{-1} yr^{-1})
Tilapia	3	300	7200	5700
	1.5	600	7200	6450
Tambaquí	1.5	600	7200	6450
	0.9	1000	7200	6750
Pacu	1.5	600	7200	6450
	0.9	1000	7200	6750
Carp	1.25	600	6000	4750
	0.5	1500	6000	5500

constant pond area of 2000 m^2 and a depth 1.2 m. Consequently, pond volume was assumed to be constant (i.e., 2400 m^3).

One-year simulations were conducted for each cell within the grid for Latin America using a one-day time step, and the resulting daily water temperature values were averaged for each month. The latter set of values was then used to generate maps of monthly mean water temperature. To test water temperature conditions < 0˚C, a condition was inserted during map creation to plot the mean monthly air temperature. Previously the model had been tested adequately only under water temperature conditions > 0˚C.

Fish Growth Modeling

An existing fish growth model (Bolte et al., 1995; see also Nath, 1996) was modified for use in this study. The model was parameterized for all four species according to Bolte and Nath (1996), and one-year simulations were conducted across the entire Latin American grid. Daily water temperatures required for the growth model were obtained by linear interpolation of monthly means predicted by the water temperature model discussed above.

It was necessary to make minor modifications to the growth model in order to generate crops/y output. For example, it is difficult to specify exact stocking and harvest times for simulation runs that are relevant to a large geographical region because the time period required to reach the desired harvest size varies among locations. Further, depending on temperature preferences of different species, fish culture may be possible only during a certain period in the year. This is difficult to predict *a priori*; therefore, it was assumed that a fish lot (population) would be stocked when water temperatures were favorable. Favorable water temperature was arbitrarily defined as a 15-day period when temperatures are within the range necessary for the growth of a particular fish species. The desired harvest weight for each species was also specified before a simulation run commenced.

During the simulations, the fish population was “harvested” if any of the following conditions were encountered:

- The specified harvest weight (implying a full crop) was reached before completion of one year;
- The simulation duration of one year was reached without registration of one or more crops; or
- Water temperatures were unfavorable for growth.

In the first case, if water temperatures continued to be suitable for the selected fish species, it was assumed that an additional fish lot would be stocked and harvested according to the above conditions. In the second and third cases, the crops/y output was expressed as a decimal fraction of the current fish weight relative to the harvest weight (i.e., a partial crop was reported). The simulation procedure is summarized in Figure 1.

Commercial Farming

In order to explore a range of commercial aquaculture possibilities by the use of the growth model, simulations were conducted for all four fish species assuming two different feeding levels and

Table 2. Stocking sizes, densities, and harvest sizes (small and large) assumed within each of the small-scale farming scenarios for tilapia and carp. Expected gross and net yields (after accounting for mortality) for a hypothetical output of one crop/y are also shown.

Species	Stocking Density (fish m^{-2})	Stocking Size (g)	Harvest Size (g)	Gross Yield (kg ha^{-1} yr^{-1})	Net Yield (kg ha^{-1} yr^{-1})
Tilapia	2	25	150	2400	1900
Carp	1	50	350	2800	2300

two harvest weights. Natural food availability was assumed to be negligible. Feed application rates required for 50% and 75% satiation were assumed to represent commercial aquaculture operations with low and high feeding rates, respectively. The primary effect of higher feeding rates, according to the model, increases fish growth and thus allows target size to be reached earlier. The advantage of using percent satiation feeding levels instead of feeding rates on a percent body weight basis is that the former approach takes into account variations in the factors affecting fish appetite during calculation of feed requirements. Within each of the percent satiation feeding levels, two harvest weights (small and large) were also established in consideration of market preferences for each of the fish species.

The stocking weight for tilapia, tambaquí, and pacu was assumed to be 50 g for all the scenarios; carp were stocked at 100 g. A survival rate of 80% was assumed for all the simulation runs. Additional parameters assumed for commercial farming are indicated in Table 1.

To achieve the overall objectives of the GIS study and for easy interpretation of the results, it was necessary to aggregate crops/y outputs from the simulation runs into four classes. However, specification of rigid classes that pre-judge the value of the output without accompanying production cost and marketing data would not be appropriate. Furthermore, differences in model output were expected depending on the particular species, harvest size, and feeding levels. To avoid these problems, output for each simulation scenario was divided into equal quarters of the range of crops/y. They are designated as 1st quarter, (highest crop/y), 2nd quarter, (2nd highest crop/y), etc.

Small-scale Farming

It is difficult to precisely define small-scale, subsistence-level aquaculture operations because of the wide variety of materials used as inputs to these systems and the variation of fish sizes that are harvested. In general, however, such systems are characterized by low intensity management and smaller sizes of fish at harvest. Analysis of the potential for small-scale farming was limited to tilapia and carp. These two species effectively utilize natural food resources in ponds, whereas tambaquí and pacu perform well primarily in ponds that receive artificial feed of relatively high quality.

Natural food availability was modeled as a function of fish biomass (Bolte et al., 1995). This approach requires definition of the critical standing crop (kg ha^{-1}) or critical fish biomass (CFB) (kg m^{-3}). For tilapia ponds that are not heavily fertilized or fed, a CFB of about 0.075 kg m^{-3} (equivalent to a fish biomass of 750 kg ha^{-1}) appears to be reasonable (Bolte et al., 1995). This value was also assumed for carp ponds in this study.

Parameters assumed for the simulation of both species under small-scale farming conditions are indicated in Table 2. These simulations assumed a survival rate of 80%.

Model output as crops/y for tilapia and carp under small-scale simulation conditions was also divided into equal quarters (as described in the section on commercial farming above).

Results

Yield in terms of crops/y was the key output of the growth model for the four different fish species. This output is presented first from a continental viewpoint and then from a country viewpoint. The continental results are expressed in terms of the total surface area. For simplicity, crops/y results were separated into quarter parts of the ranges that have been attained with each feeding rate-harvest weight combination. Only a brief overview of the results is presented here because complete documentation including maps of crops/y output for individual species is available elsewhere (Kapetsky and Nath, in prep.).

Continental Level

Relatively large areas of Latin America were shown to be suitable for the commercial farming of the four species considered in this study. For example, areas in which first (i.e., highest) quarter crops/y were attainable ranged from a high of 73% in Latin America for carp to a low of about 34% for Nile tilapia; however, one result for Nile tilapia was only 9%. Results for individual species ranged from 66 to 73% for carp, 55 to 66% for tambaquí, 48 to 60% for pacu, and 9 to 43% for Nile tilapia.

Areas corresponding to second and third quarter crops/y were relatively small. Thus, significantly, most of the area suitable for farming these four species seems capable of producing relatively high numbers of crops/y in each feeding rate-harvest weight combination.

Within individual species results, there was relatively little difference among the first quarter surface areas that resulted from different feeding rate-harvest size combinations. Rather, it was the numbers of crops/y that varied markedly when the different regimes were simulated. As would be expected, it was the combination of low feeding rate and high harvest weight that produced the least crops/y. In general, among the four species, feeding at the high rate (75%) and harvesting at the low weight provided the best results in terms of relatively large surface areas and the highest number of crops/y.

Feeding at 75% and harvesting at the high weight produced the second best combination of high crops/y along with large surface areas. The same pattern applied to Nile tilapia; however, for carp slightly higher crops/y were attained with 50% feeding and the low harvest size.

A somewhat surprising result generated by the fish growth model showed that the number of crops/y of pacu tended to exceed that of tambaquí in regions where water temperatures were relatively warm. This was unexpected because water temperatures appeared to be more favorable for the latter species.

For small-scale farming, the results varied considerably between the two species considered. For a relatively small area of Latin America (34%), Nile tilapia harvested at 150 g can yield 1.3 to 1.7 crops/y and an additional 13% of the surface area can produce 0.9 to 1.3 crops/y. In contrast, 70% of the continent can produce 1.4 to 1.8 crops/y of carp harvested at 350 g and an additional 12% of the area can produce 0.9 to 1.4 crops/y.

Country Level
Commercial Farming

In this section we present the spatial distribution of species potential from a country by country viewpoint in the form of histograms that indicate the relative surface area applicable to each country. Within each species, the spatial patterns are similar for each feeding rate-harvest weight combination; therefore, only one histogram per species is presented herein.

Tambaquí

First quarter crops/y for this species were possible in Southern Mexico, in nearly all of the Central American countries, throughout the northern countries of South America, and over much of Brazil and parts of Peru, Bolivia, and Paraguay (Figure 2). North Central Mexico, Uruguay, Chile, and all but northern Argentina were disadvantaged.

Pacu

The spatial pattern for pacu was similar to that of tambaquí but more restricted. First quarter crops/y areas were less, and second quarter crops/y areas were larger (Figure 3).

Nile tilapia

The spatial distribution for commercial culture opportunities of Nile tilapia was markedly more restricted than for the other species; however, the same group of Central American and north and northwest South American countries maintained first quarter crops/y potential. Much of the relatively high yield potential was lost in the marginal countries (Figure 4).

Carp

As would be expected for a species with a relatively wide temperature range for growth, the spatial distribution for carp culture was greater compared to the other species (Figure 5). For example, first and second quarter crops/y ranges

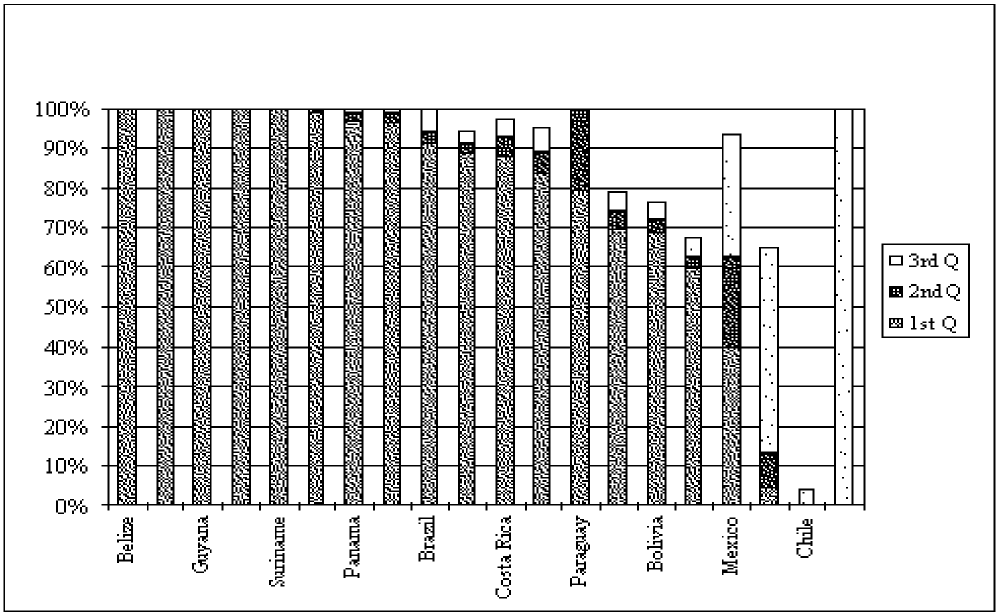

Figure 2. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of tambaquí fed to 75% satiation and harvested at 600 g.

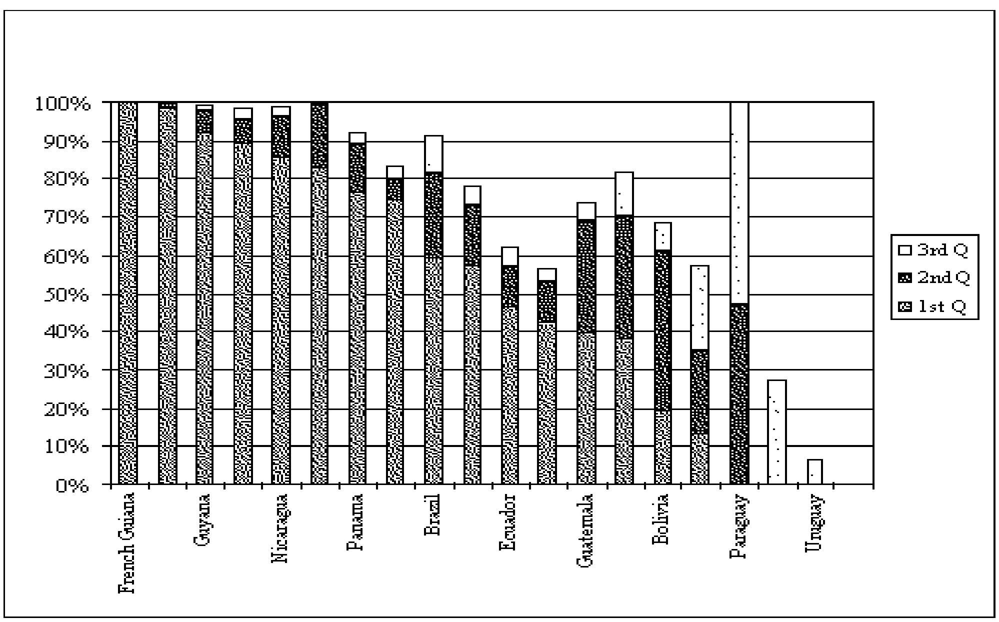

Figure 3. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of pacu fed to 75% satiation and harvested at 600 g.

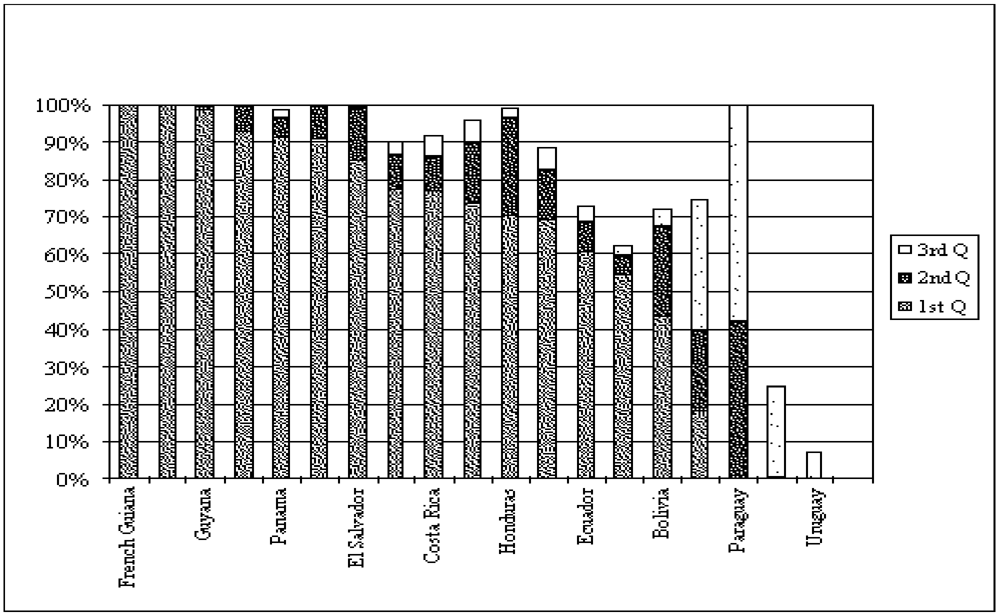

Figure 4. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of Nile tilapia fed to 75% satiation and harvested at 300 g.

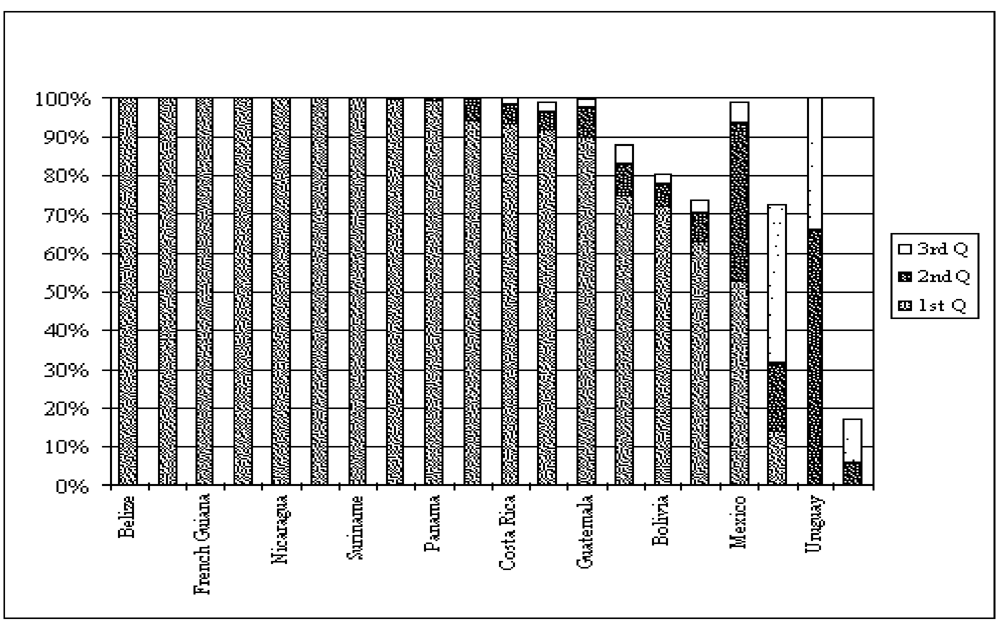

Figure 5. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of common carp fed to 75% satiation and harvested at 600 g.

could be realized over much of Mexico and in Northern Argentina, whereas only small areas of these regions were suitable for the other three species.

Country Level
Small Scale Farming

Carp and Nile tilapia contrasted greatly in the spatial distribution of their small-scale culture potential. Nile tilapia was suited for small-scale farming in the same countries as carp, and first and second quarter crops/y ranges were similar to those of the carp; however, tilapia potential extended over a smaller area (Figures 6 and 7). Nevertheless, first quarter crops/y (1.3 to 1.7) could be obtained in 50% or more of 11 countries. Only Uruguay and Chile offered no possibilities for yields in the first and second quarter ranges. Opportunities for small-scale farming of carp were extensive. First quarter yields ranging from 1.4 to 1.8 crops/y could be attained from more than 50% of the areas of all but three of the countries, and only Chile was quite disadvantaged.

Discussion and Conclusions

This study is the first attempt to integrate a fish growth model within a continental-scale GIS to predict the number of fish crops possible per year. The results suggest that such integration is a useful mechanism to address the effects of various factors (primarily water temperature and feeding rates) on fish yields and to estimate the production potential at various levels of culture intensity. The approach may also be applicable to the analysis of pond aquaculture potential at different geographical scales (e.g., for single countries, or states/districts within individual countries). Moreover, the parameterization of the fish growth model developed by Bolte et al. (1995) for various species proved to be very beneficial.

As indicated previously, crops/y output obtained for tambaquí and pacu were somewhat unexpected for the warmer waters of Latin America, because the former species generally grows more rapidly in waters ranging from 25 to 35°C (e.g., Saint-Paul and Werder, 1980; Saint-Paul, 1989). Although some experiments (e.g., Miyasaka and Castagnolli, 1992) have shown that pacu may grow better than tambaquí in mean water temperatures ranging from 27 to 30°C, we suspect that the crops/y results obtained for these species may in part be due to the lack of sufficient growout data to better parameterize the growth model for tambaquí (see also Nath, 1996). The higher crops/y output registered from Central Brazil southward for pacu compared with tambaquí is perhaps not surprising because pacu appear to better tolerate colder temperatures than tambaquí (Saint-Paul, 1989).

In general, the results were quite positive for the development of inland fish farming in Latin America because large areas of the continent were shown to be suitable for the farming of a variety of species. The numbers of crops per year could be maximized through a combination of relatively high feeding rates and harvest at moderate weights.

It should be noted, however, that not all of the potential aquaculture areas identified for one or more of the species used in this study will be available for aquaculture development. In addition to growth potential, some of the areas may not be appropriate because of a variety of other factors (water requirements, urban market potential, potential for farm gate sales, availability of agricultural by-products as feed/fertilizer input, and engineering and terrain suitability for pond construction) necessary to determine site suitability for pond aquaculture. The fish growth model predictions obtained in this study were combined with analyses of these additional factors within GIS to identify areas of Latin America that are either very suitable, suitable, marginally suitable, or unsuitable for aquaculture development. Further, regions unavailable for inland fish farming development were identified by incorporating constraints such as protected areas, large inland water bodies, and urban centers. Complete details of these analyses are given in Kapetsky and Nath (in prep.).

Finally, additional improvements such as use of stochastic weather data to investigate the best and worst climate situations, as well as the average situation for the production of fish, may be useful in future assessments of aquaculture potential for large geographic areas. Such analysis could include inter-annual temperature variations as they affect growth and associated yields. It may also be useful to extend the range of species considered to include cold-water candidates and to examine the potential for other fish production systems including polyculture, recirculation systems, and flow-through facilities.

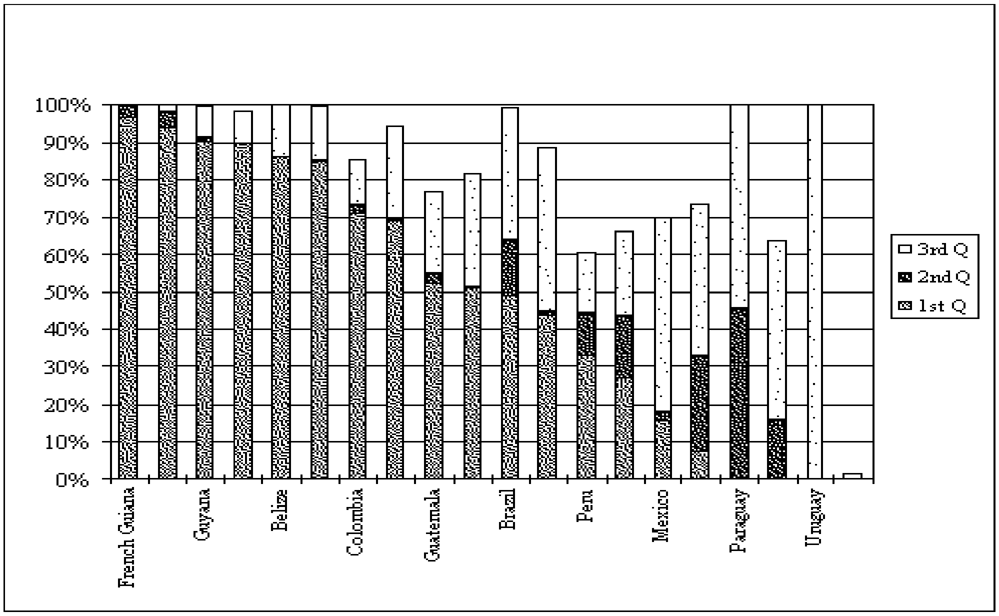

Figure 6. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of Nile tilapia under small-scale farming conditions.

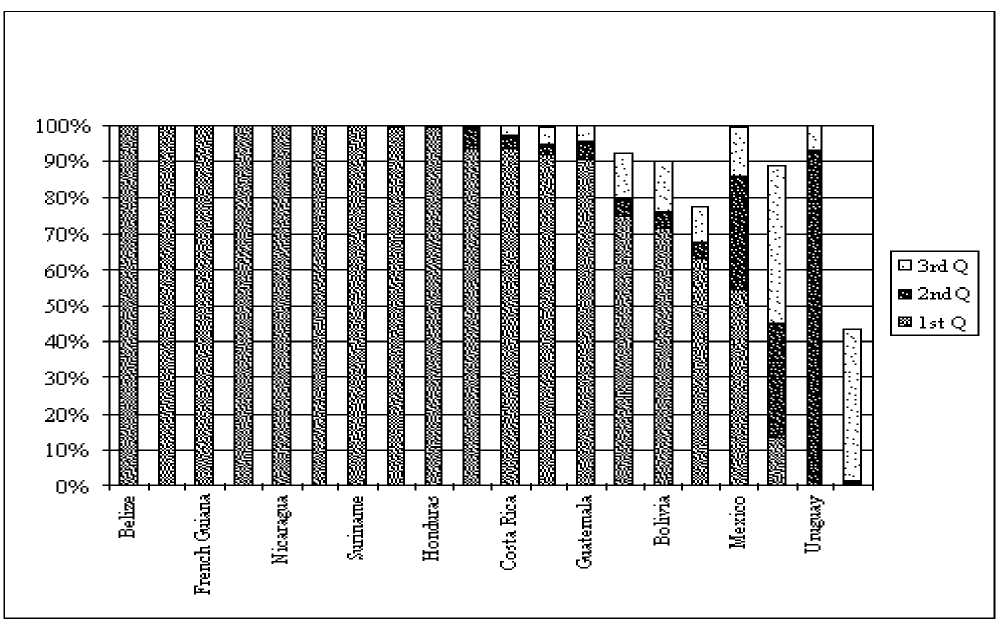

Figure 7. Relative area (%) of continental Latin American countries capable of producing first, second, and third quarter crops/y of common carp under small-scale farming conditions.

Anticipated Benefits

This study has demonstrated that the integration of water temperature and fish growth models is a useful mechanism for generating yield estimates of different fish species at a continental scale. The approach will also be useful for analyses of aquaculture potential at different geographical scales (e.g., within specific countries, or states/districts within individual countries). Fish yield estimates obtained in this study demonstrate the high potential for pond aquaculture in the inland regions of Latin America. In addition, these estimates were combined with other important factors relevant to fish farming suitability within a GIS. The ensuing outputs of this study are expected to be very useful in strategic planning for aquaculture development at national levels, and as a tool to guide technical assistance activities by international organizations.

Acknowledgments

The assistance of Fabio Grita (FAO GIS Centre) in conducting GIS analyses and simulation runs with the water temperature and fish growth models is gratefully acknowledged. Funding for this study was provided both by the FAO Inland Water Resources and Aquaculture Service and by the PD/A CRSP.

Literature Cited

Bolte, J.P. and S.S. Nath, 1996. Decision support for pond aquaculture: Parameter estimation techniques. In: H. Egna, B. Goetze, B. Herbison, M. McNamara, and D. Clair (Editors), Thirteenth Annual Administrative Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Corvallis, OR, USA, 96 pp.

Bolte, J.P., S.S. Nath, and D.H. Ernst, 1995. POND©: A decision support system for pond aquaculture. In: H. Egna, M. McNamara, and N. Weidner (Editors), Twelfth Annual Administrative Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Corvallis, OR, USA, 95 pp.

Fritz, J.J., D.D. Meredith, and A.C. Middleton, 1980. Non-steady state bulk temperature determination for stabilization ponds. Water Research, 14:413-420.

Kapetsky, J.M., 1994. A strategic assessment of warm-water fish farming potential in Africa. CIFA Technical Paper 27, FAO, Rome, 67 pp.

Kapetsky, J.M. and S.S. Nath, in prep. A fish farming GIS for Latin America. CIFA Technical Paper, FAO, Rome.

Lovshin, L.L., 1995. The Colossomids. In: C.E. Nash and A.J. Novotny (Editors), Production of Aquatic Animals: Fishes. World Animal Science C8, Elsevier, Amsterdam, The Netherlands.

Miyasaka, A.M., and N. Castagnolli, 1992. Teste comparativo de desempenho entre pacu (*Piaractus mitrei*), tambaquí (*Colossoma macropomum*) e seus hibridos reciprocos "paqui" e "tambacu." SIMBRq., 7:82-93.

Nath, S.S., 1996. A decision support system for pond aquaculture. Ph.D. Dissertation, Department of Bioresource Engineering, Oregon State University, Corvallis, OR, USA.

Nath, S.S., J.P. Bolte, and D.H. Ernst, 1995. Decision support for pond aquaculture planning and management. Sustainable Aquaculture '95, PACON International, 11-14 June 1995, Honolulu, Hawaii, USA.

Saint-Paul, U., 1989. Indigenous species promise increased yields. NAGA, January 1989, pp. 3-5.

Saint-Paul, U. and U. Werder, 1980. The potential of some Amazonian fishes for warm water aquaculture. Proc. World. Symp. on Aquaculture in Heated Effluents and Recirculation Systems, Vol. II., pp. 275-287.

Applications of POND© as a Tool for Analysis and Planning

Interim Work Plan, DAST Studies 1 and 2

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Introduction

POND© provides a useful framework for synthesizing knowledge about pond aquaculture and presenting it in a form that can be used for decision support (Bolte et al., 1995). In a previous PD/A CRSP report (Nath et al., 1996), modifications made to the software since the first release (Version 2.0) were presented. The applications of such modifications for pond aquaculture planning and management are the focus of this report. Additionally, the results of ongoing model verifications and sensitivity analyses are presented.

POND© Applications

Assessment of Water Requirements

Development of pond water budgets is important from the perspectives of estimating water requirements for ponds that rely on rainfall events and runoff as primary water sources (Boyd, 1982) and for flow-through pond facilities (which mainly use levee ponds). Water budget analysis may also be useful in comparing the value of available water for different agricultural crops as suggested by Green and Boyd (1995) and may have implications for examining the environmental effects of pond water discharge due to either intended water release or overflow.

Although various research efforts have focused on developing water budgets for different pond aquaculture systems, the general methodology used in these studies has not been presented in the form of a model that can be easily adapted to new locations as a general purpose tool for forecasting water budgets over long-term periods. Such a model that includes various sources and sinks (Figure 1) has been developed and implemented in POND©.

The model has been validated for ponds located at the Asian Institute of Technology (AIT), Thailand, and at El Carao, Honduras, which are respectively located in humid and dry tropical regions. Simulation results indicate that precipitation accounted for 69.8% of the total water gains for AIT and 43.2% for El Carao. Similarly, regulated inflow provides 27% of the gains for AIT and 52.8% for El Carao. Runoff gains were minimal at both locations, presumably a result of small watershed areas. Evaporation accounted for 54.9% and 40.1% of the overall water loss predicted for the AIT and El Carao locations while seepage accounted for the remaining loss. The difference between actual and predicted amounts of regulated water inflow for the AIT pond was only 20.3 m^3 over a simulation period lasting five months. For El Carao, predicted water requirements were 141.3 m^3 lower than the amounts actually added, apparently due to poor estimates of evaporative water loss, which averaged 0.32 cm d^{-1} compared to pan evaporative measurements of 0.43 cm d^{-1}. In contrast, the predicted evaporative water loss for the AIT pond (0.47 cm d^{-1}) was very comparable to the pan evaporation estimate of (0.45 cm d^{-1}) for this site.

More complete weather datasets for AIT (which included measurements, such as cloud cover and relative humidity, that are not routinely reported in the CRSP Central Database, but were retrieved from an international weather station in the vicinity of the ponds) compared to El Carao appear to explain the higher accuracy in evaporative water loss estimates for the former site. If such comprehensive weather datasets are available for different locations, the water budget model shows considerable potential for the estimation of water requirements during the planning and operational phases of individual aquaculture facilities. For instance, the model can

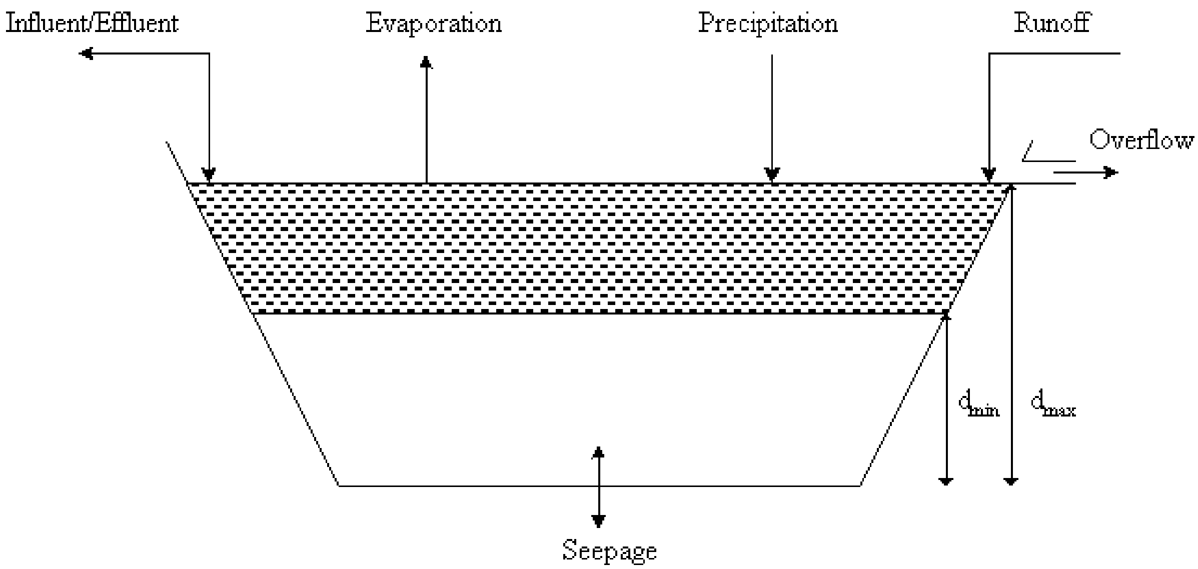

Figure 1. Schematic diagram showing the types of water sources and sinks that can be considered in the POND© water budget model, d_{min} and d_{max} respectively refer to the minimum desired and maximum possible pond water depth.

be used for pond aquaculture farms in the United States (e.g., for catfish, baitfish, and striped bass), particularly because more complete weather datasets are likely to be available for areas in the country where such farms are likely to be located.

The model can also be applied to regional-scale analysis of pond aquaculture water requirements and can be used as a tool to compare the benefits of water use for aquaculture relative to other agricultural practices. Analysis of water budgets for AIT and El Carao also suggests that the PD/A CRSP weather data collection protocols should be expanded to include measurements of cloud cover and relative humidity. If such measurements are available, it may not be necessary to routinely collect pan evaporation data, because the POND© water budget model can be used to estimate daily water losses. Further, the additional weather data are likely to be beneficial to researchers from the University of California at Davis who are involved in the validation of stochastic models of stratified pond systems over long-term periods.

Assessment of Fertilizer Requirements

Previous verification of the PONDCLASS fertilization guidelines was fairly successful in the Philippines (Hopkins et al., 1994) and Thailand (Hopkins and Knud-Hansen, submitted) in that the amount of fertilizer required to produce one unit of fish production was typically lower compared to control treatments or prevailing practices. Similar results were obtained in Thailand as part of the Global Experiment undertaken during the Seventh Work Plan of the PD/A CRSP (Szyper and Hopkins, 1995).

However, fish growth in Honduran ponds that were managed using PONDCLASS guidelines (Teichert-Coddington and Ramos, 1995) appeared to be limited by the build-up of ammonia nitrogen (NH_3-N). Reasons for high NH_3-N concentrations at this location are unclear, but they may in part be due to the use of a maximum net primary productivity (NPP_{max}) value of 4 g C m^3 d^{-1} that appears to be high—at least in terms of consistent primary productivity—for this location and which may have resulted in excessive N loading. In contrast, Szyper and Hopkins (1995) typically set NPP_{max} to 3 g C m^{-3} d^{-1} in the PONDCLASS software while estimating weekly fertilizer needs at the Thailand site where primary productivity is usually higher than at the Honduras site. Additionally, the effects of high NH_3-N concentrations on fish growth at the latter site were presumably amplified because of relatively high pH values in the range of 8 to 10 (Teichert-Coddington and Ramos, 1995). At these pH values, the fraction of NH_3-N that exists in the toxic, unionized form would be quite high (Emerson et al., 1975). Finally, the poor results obtained with PONDCLASS at Honduras may also have been due to inadequate consideration of nutrient cycling within the

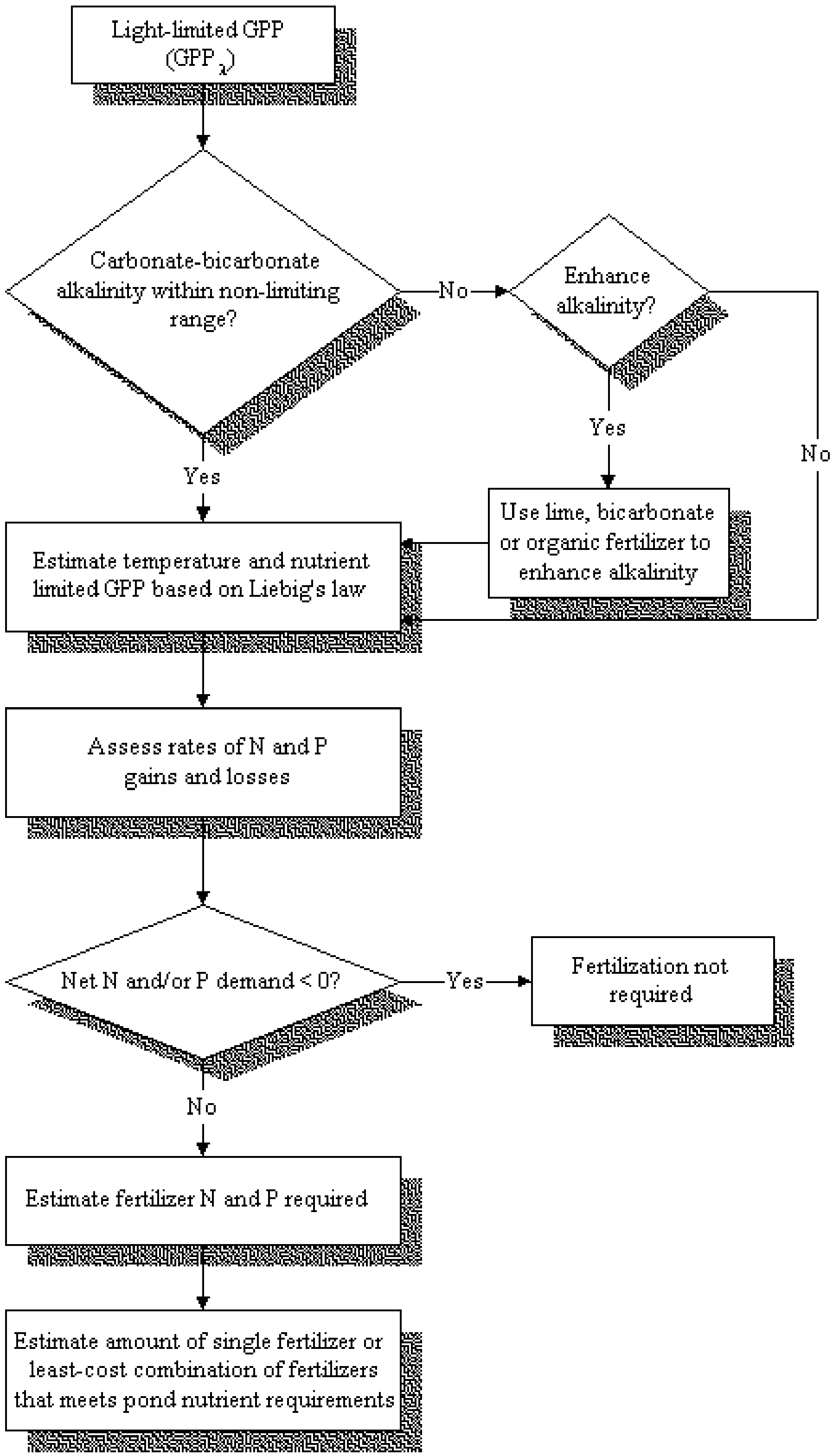

Figure 2. A summary of the POND© fertilization model that can be used to assess nutrient requirements of ponds, and estimate associated fertilizer needs over short-term simulation periods (one to two weeks).

software. Water quality data for the PONDCLASS experiment in the Philippines (Hopkins et al., 1994) also indicate frequent occurrence of high total ammonia concentrations.

Examination of PD/A CRSP data for PONDCLASS-treated ponds thus suggests that the guidelines developed by Lannan (1993) may recommend unexpectedly high fertilizer application rates even though ambient nutrient concentrations may already be in excess of amounts needed for rapid algal growth. This appears to be primarily due to inadequate consideration of algal growth potential and nutrient cycling processes in ponds. These limitations of PONDCLASS have been addressed in a fertilization model that has been implemented in POND©.

The model assumes that a maximum level of gross primary productivity (GPP_l), limited only by light availability, is possible for any pond. The effects of nutrient concentrations on algal growth rate are assessed using Michaelis-Menten kinetics, whereas a skewed normal function is used to describe temperature effects. Liebig's minimum factor rule is used to approximate the combined effect of temperature and nutrient levels on algal growth, which when applied to GPP_l provides an estimate of the realized GPP for a given pond. The carbonate-bicarbonate alkalinity of pond water is assumed to be the main source of inorganic carbon. Simplified mass balance equations are developed to account for processes that affect nitrogen and phosphorus concentrations. The primary sink for these nutrients is assumed to be algal uptake, whereas algal respiration and fertilizer addition are the main sources. An additional term that accounts for miscellaneous processes (fish uptake, sediment exchange, etc.) by the use of first-order kinetics, and which may be either a nutrient source or sink, is also considered. For nitrogen, available data suggest that there is a net overall gain of this nutrient via the above processes, whereas phosphorus is generally lost from the pond water to the underlying sediments. The steps involved in evaluating nutrient requirements and generating fertilizer application rates by the use of the POND© fertilization model are summarized in Figure 2.

Model verification was undertaken by comparing fertilizer application data obtained from PONDCLASS-treated ponds in El Carao (Honduras), AIT (Thailand), and the Freshwater Aquaculture Center (FAC, Philippines) to those generated by the fertilization model. This comparative analysis indicates that the fertilization model generates nutrient application rates that are in general more conservative than those recommended by PONDCLASS for ponds where ambient nutrient concentrations are already fairly high (Table 1). However, recommendations obtained from both approaches are comparable when ponds require high dosages of nitrogen and/or phosphorus to ensure rapid algal productivity rates (Table 1). Model verification results are consistent with previous work (e.g., Knud-Hansen and Guttman, submitted; Hopkins and Knud-Hansen, submitted) in that responsive fertilization strategies (i.e., strategies that take into account ambient pond water conditions during evaluations of pond nutrient needs) are likely to be superior in terms of cost and fertilizer use efficiency compared to the more traditional fixed input strategies. Further, because nutrient concentrations in pond water vary substantially over time, it is highly unlikely that fixed application rates of nitrogen, phosphorus and/or carbon fertilizers, which are expected to be economically optimal, can be determined for the entire duration of a culture cycle. The term "economically optimal," within the context of this study, is used to indicate fertilizer application rates which result in the highest economic efficiency measured in terms of fertilizer costs required to produce one unit of fish. The term does not address alternate uses of the fertilizers in terrestial crop production. Arguments in support of responsive management strategies are further strengthened by the fact that, in addition to the variability of nutrient concentrations in a given pond with time, there is also variability among ponds at a given site, as well as among geographical locations as a result of differences in pond water, soil, and climatic characteristics.

During a visit to baitfish farms in the Southern United States (in the vicinity of Pine Bluff, Arkansas) by one of the OSU-DAST researchers, a frequent problem mentioned by extension agents and farmers alike was the lack of appropriate fertilization guidelines for the different source water and soil types in the region. Most of the fertilizer application rates recommended by extension agents are based on experimental data generated at locations with very different water and soil characteristics. These rates have apparently not produced acceptable results at new locations. Because the POND© fertilization model takes into account climatic, water, and soil characteristics in generating fertilization rates, it

Table 1. Weekly fertilizer recommendations generated by PONDCLASS at El Carao, AIT, and FAC compared to those obtained from the model developed in this study (indicated in parentheses). PONDCLASS fertilizer application rates and water quality data were extracted from the PD/A CRSP Central Data Base. Mean GPP predicted by the use of the POND© fertilization model is also shown.

Date[a]	Mean GPP ($g C m^{-3} d^{-1}$)	Ambient Nutrient Concentrations ($g m^{-3}$)			Nutrient Requirements ($g m^{-3} wk^{-1}$)[d]			Weekly Fertilizer Recommendations ($kg ha^{-1} wk^{-1}$)	
		DIN	*DIP*[b]	*DIC*[c]	*N*	*P*	*CM*[e]	*Urea*	*Other*[f]
El Carao									
May 25	3.50	0.04	1.50	11.0	2.21 (15.75)	0	230 (0)	(35.0)	0 (0)
June 29	4.33	1.97	0.95	23.4	0.07 (0.53)	0	230 (0)	(1.1)	0 (0)
Aug 10	3.98	0.31	0.49	15.7	2.22 (15.82)	0.07 (0.52)	206 (0)	(34.2)	0 (0)
Sept 18	4.26	0.89	0.25	21.3	(12.43)	0.25 (1.75)	240 (0)	61.7 (24.0)	0 (7.7)
AIT									
Jan 24	6.38	0.06	0	34.8	4.04 (29.74)	0.68 (4.99)	437.7 (582.7)	56.9 (51.6)	0 (0)
Feb 04	4.87	0.31	0	35.4	(20.58)	0.52 (3.81)	242.5 (210.2)	38.0 (40.4)	0 (0)
Feb 11	6.20	0.92	0	27.3	2.98 (21.98)	0.66 (4.85)	242.5 (266.7)	47.6 (42.1)	14.1 (0)
Apr 08	6.10	1.13	0.02	24.4	(19.64)	0.63 (4.85)	242.5 (266.7)	47.6 (42.1)	14.1 (0)
FAC									
Jan 15	5.58	0.66	0.45	43.6	(21.90)	0.24 (1.82)		72.0 (41.2)	14.8 (21.1)
Jan 29	5.61	2.41	0.79	47.4	(3.07)	0.06 (0.42)		46.0 (4.9)	0 (5.3)
Feb 12	5.14	0.19	0.15	22.0	(23.67)	0.40 (3.15)		(39.8)	(36.0)
Feb 26	5.42	2.52	0.93	32.0	0	0		44.0 (0)	0 (0)

[a] Dates of fertilizer application. PONDCLASS experiments were conducted in 1993 at El Carao and FAC and at AIT in 1994.
[b] Zero DIP values in the PD/A CRSP Central Database for AIT presumably indicate negligible concentrations of soluble ortho-phosphate.
[c] Calculated from pH, alkalinity and water temperature data.
[d] Weekly nutrient requirements predicted by the use of POND©. Data in parentheses are requirements expressed in $kg ha^{-1} wk^{-1}$.
[e] CM = chicken manure on a wet weight or as-is basis. This fertilizer was used only at El Carao and AIT.
[f] Refers to other synthetic fertilizers that were used principally for P supplementation. These included DAP (diammonium phosphate) at El Carao, TSP (triple superphosphate) at AIT, and a 16-20-0 mix at FAC.

should have widespread applications for baitfish farms located in the Southern United States.

As with any computer-assisted management tool, users of the POND© fertilization guidelines should observe certain precautions when the software is used. For instance, although the effects of nutrient cycling are considered in the fertilization model, fairly high application rates of N can still be suggested, particularly for locations where algal productivity is likely to be high (e.g., results for AIT in Table 1). If urea is chosen to meet this demand and its use is prolonged, fairly high pH values and total ammonia levels may occur simultaneously in ponds. Because the toxicity of unionized ammonia varies among fish and crustacean species (Colt and Armstrong, 1981), tables such as those provided by Emerson et al. (1975; see also Boyd, 1990) should be used to determine the proportion of total NH_3-N that exists in the unionized form for the ambient water pH and temperature. If the potential exists for growth-limiting concentrations of unionized NH_3-N for the cultured fish species, then alternate N sources should be used or fertilization with synthetic nitrogenous fertilizers should be suspended for a few days so that NH_3-N concentrations can drop to levels that are safe for fish.

As a general rule, available data suggest that fertilization with synthetic nitrogen sources should be deferred if total ammonia levels exceed about 1.0 mg l^{-1} and water pH values are routinely higher than about 8.0. During periods when local weather conditions (e.g., prolonged cloudy days) result in decreased light, nitrogen fertilization rates should be adjusted downward. Overcast weather conditions are likely to impede phytoplankton growth—plankton blooms may crash because of reduced nitrogen uptake—and lead to the accumulation of ammonia-N in the pond.

Despite the encouraging results obtained with the fertilization model, field verification of its recommendations should be undertaken in the form of pond experiments designed to enable estimation of various parameters used in the fertilization model. In particular, it would be beneficial to develop nutrient budgets for locations with diverse pond water and soil conditions and to estimate the rates of nutrient fluxes. This is particularly important for nitrogen because very little is known about the fate of this nutrient in aquaculture ponds. For phosphorus, there is much evidence to suggest that it may in fact be returned to the water column at relatively high rates once equilibrium has been established between the pond water and the underlying sediments after long periods of heavy phosphorus fertilization (e.g., Eren et al., 1977; Boyd, 1995; Shreshtha and Lin, 1996). Under such conditions, there will actually be a gain of phosphorus via miscellaneous processes, with an associated rate constant that is likely to vary depending on the soil type and its phosphorus adsorption capacity. Experiments should also be conducted at different locations to examine ranges of nutrient addition, to develop associated GPP-nutrient relationships, and to evaluate economic consequences of forcing ponds to be nutrient limited. For instance, it may be advisable to reduce nitrogen loading rates in order to minimize the possibility of unionized ammonia accumulation. Further, it may also be useful to vary N:P ratios in ponds either for cost concerns or to manage the composition of algal species in ponds.

Assessment of Feed Requirements

In this section, we discuss the applications of the POND© bioenergetics (BE) model to 1) assess fish growth and feed requirements in fertilized and unfertilized ponds and 2) examine the effects of feed quality on these requirements. All the simulation runs were performed using the Level 1 modeling option in POND©.

Supplemental Feeding in Fertilized Ponds

Two key elements of any supplemental feeding strategy for pond aquaculture systems include: (i) initiation of feed addition, and (ii) quantity of feed to be added. For species such as tilapia and carp that efficiently use natural food resources in fertilized ponds, the arguments of Hepher (1978) and several CRSP researchers (e.g., Teichert-Coddington et al., 1990; Green, 1992) strongly suggest that supplemental feed addition is not required until the critical standing crop or fish biomass (CFB) for a pond is reached.

Although it is necessary to specify the CFB for a pond prior to a simulation run, the BE model can be used to determine when feed addition should commence at various locations. This is because the model accounts for differences in fish growth rates caused by variations in environmental conditions among geographical regions. Consequently, the time period required to reach CFB (as predicted by the model) also varies from region to region, and can be used to determine when supplemental feeding should be initiated.

With regard to the amount of feed required, available feeding tables for fish such as tilapia and carp suggest that feeding rates (on a %BW basis) in ponds should decline with increasing fish weight. Although this is certainly true for situations where the artificial feed is the primary source of nutrition (because the relative food requirement of fish decreases as they grow), it is not clear whether such feeding rates are appropriate for ponds where fish continue to derive a portion of their nutritional requirements from natural food resources. Further, although authors such as Hepher (1988) indicate that supplemental feeding rates developed for a given set of conditions should be adjusted according to local conditions (primarily ambient water temperatures), it is difficult to predict how the adjustments should be made. It is also important to note that both the time period required to reach CFB and the amount of feed to be added to a pond are also functions of fish stocking density (SD). These issues can be addressed in a heuristic, if not practical, manner by the BE model.

<u>Effects of temperature</u>: Consider, for instance, the problem of estimating supplemental feed requirements for Nile tilapia culture at three sites with altitudes of 0, 500 and 1000 m above maximum sea level (MSL), respectively. For convenience, it is assumed that all the sites are located at the same

latitude and longitude as El Carao. Ponds at these sites are expected to show decreasing water temperatures with increasing elevation; therefore, fish growth rates and appetite levels are also likely to decline with elevation. Model experimental conditions were assumed to be identical to those reported by Teichert-Coddington et al. (1991).

Two sets of simulations were conducted to predict fish growth at the three sites using the weather model in POND© to provide inputs for generating water temperature profiles. For the first set of simulations, a fixed feeding rate (FFR) of 3% BW d^{-1} was provided after the first month of culture. For the second set, the fish were allowed satiation feeding rates (SFR). CFBs at MSL, 500 m, and 1000 m were assumed to be 0.20, 0.15, and 0.10 kg m^{-3}. The value of 0.15 kg m^{-3} assumed for the 500 m site was similar to that estimated for the El Carao ponds. A higher value was assumed for the site located at MSL, which was consistent with previous estimates from heavily fertilized ponds at a warmwater site in Thailand (Bolte et al., 1995). The lower value assumed for the 1000 m site reflects the likelihood of slower rates of natural food production in cooler waters.

Mean predicted water temperatures (°C) at MSL, 500 m, and 1000 m were 29.6, 26.8, and 24.1, respectively. Final predicted fish weights at these elevations for both the FFR and SFR simulations were 431.7, 340.4, and 144.2 g, respectively. Total feed requirements for the FFR simulations at MSL, 500 m, and 1000 m were 7410, 6579 and 3773 kg ha^{-1}, respectively. Corresponding food conversion ratios (FCR) were 2.15, 2.52, and 4.01, respectively. For the SFR simulations, feed requirements at the three elevations were 1913, 1742, and 455 kg ha^{-1}, respectively. Similarly, FCRs were 0.55, 0.67, and 0.48.

Results of the FFR simulations suggest that this practice is likely to be economically inefficient, presumably because it does not take into account the proportion of natural food in the diet of pond fish, and changes in fish appetite caused by increasing size and varying temperature conditions. Apart from economic considerations, wasted feed also contributes to poor water quality in ponds, which can depress fish growth, and may have adverse effects on the surrounding environment if water is routinely discharged from the pond facility. On the other hand, feeding curves predicted for the SFR simulations (Figure 3) take into consideration factors affecting fish appetite as well as contributions to the diet from endogenous food resources. These curves also provide some indication as to when feeding should commence at the different elevations (Figure 3). In a similar manner, the BE model should also be of use in generating supplemental feeding guidelines for locations that show seasonal differences in water temperature and photoperiod.

Effects of stocking density: In the BE model, SD does not directly impact growth rates. Rather, stocking density affects the biomass of fish in a pond, which in turn is used to estimate the parameter f_n (0-1). This parameter reflects the proportion of fish appetite satisfied by natural food in the pond. Thus, for a given CFB, ponds stocked at higher densities may be expected to reach this biomass earlier, and require larger amounts of feed thereafter if a certain satiation feeding level is to be maintained. These concepts are illustrated for Nile tilapia in the model experiments below.

Fish were assumed to be cultured over a 150-d growout period at El Carao. The CFB was set at 0.15 kg m^3. The treatments were as follows: (i) SD of 1 fish m^{-2}, no feed (SD1-NF), (ii) SD of 1 fish m^{-2}, fish fed to full satiation after the CFB is reached (SD1-F), (iii) SD of 2 fish m^{-2}, no feed (SD2-NF), and (iv) SD of 2 fish m^{-2}, fish fed to full satiation after the CFB is reached (SD2-F). The non-fed treatments were included in this analysis to compare the effects of SD and supplemental feeding on f_n as predicted by the BE model. For all the treatments, the initial stocking weight was set to 30 g, and a 90% survival rate was assumed. Pond water temperature for use in the BE model was predicted using input data from the weather generator in POND©.

Final predicted fish weights for the SD1-NF, SD1-F, SD2-NF, and SD2-F treatments were 224.0, 294.6, 147.2, and 294.6 g, respectively. These results are within the ranges for similarly treated ponds at the El Carao research station (Green et al., 1994). Of more interest, however, are profiles for the natural food index (which corresponds to f_n expressed on a percentage basis) obtained from the CFB-based function (Figure 4). As expected, these curves indicate that increasing fish biomass causes a rapid decrease in natural food availability for all treatments. However, within each of the SD treatments, this trend is more pronounced for the fed ponds. Further, supplemental feed should perhaps be added earlier in ponds stocked at higher densities (compare points A and B in Figure 4) because the CFB will be reached earlier. These

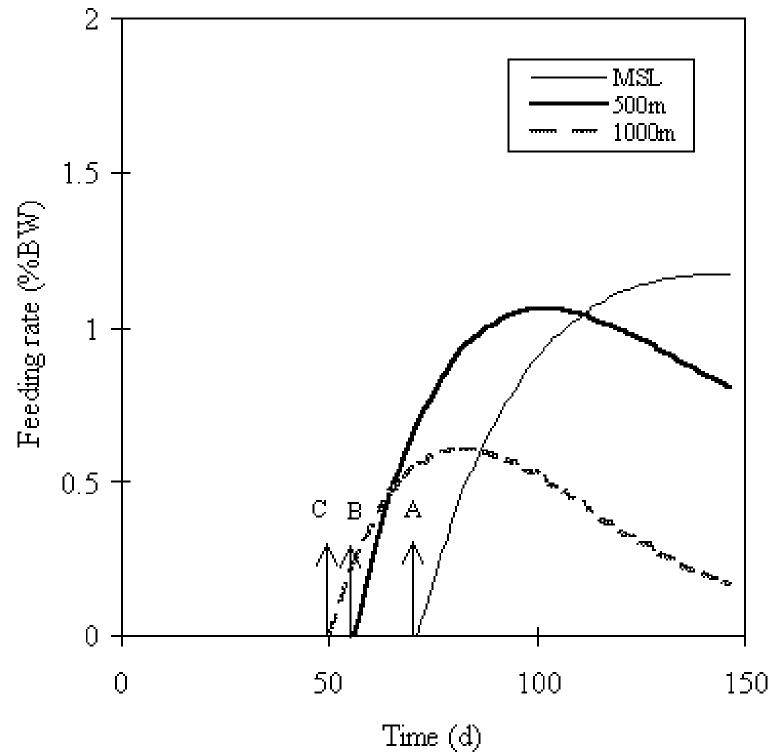

Figure 3. Feeding curves generated by the BE model for Nile tilapia that are assumed to use both natural and supplemental food resources in ponds located at three different elevations (MSL, 500 m and 1000 m). Points A, B, and C in the curves indicate when supplemental feeding should commence.

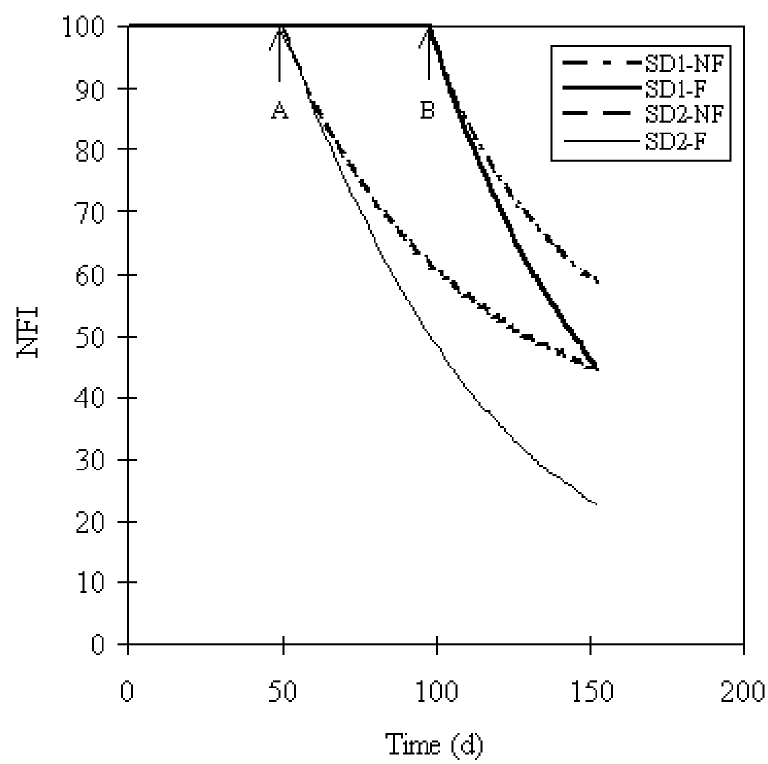

Figure 4. Natural food index (NFI) profiles for ponds stocked at 1 and 2 fish m^{-2} which either did not receive feed (NF) or were fed (F). Points A and B in these profiles appear to indicate when supplemental feeding should commence in ponds stocked at 1 and 2 fish m^{-2} respectively.

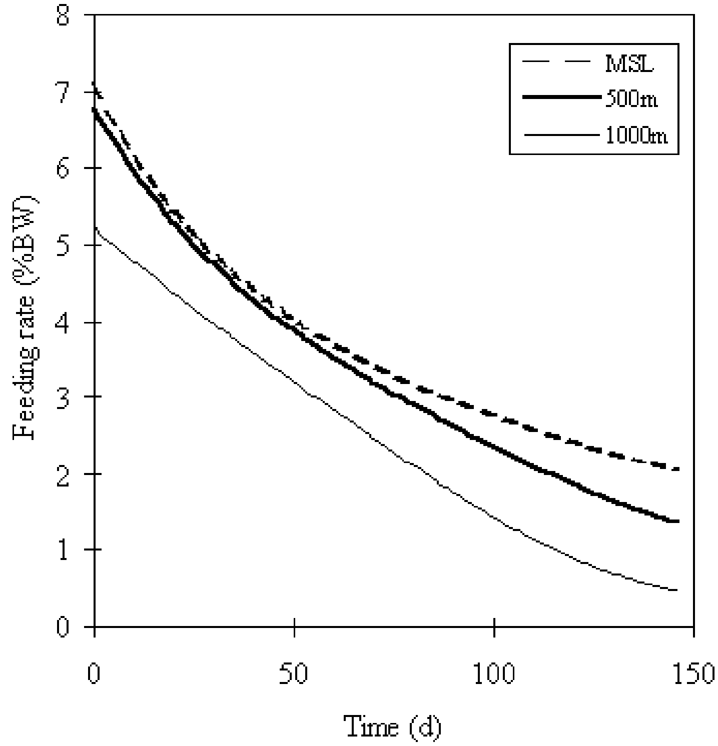

Figure 5. Feeding curves generated by the BE model for Nile tilapia that receive only artificial feed in ponds located at three different elevations (MSL, 500 m and 1000 m).

concepts have previously been described by Hepher (1978) but not illustrated in a quantitative manner. Another advantage of the BE model, of course, is that it can be used to generate such natural food index profiles for other culture conditions (e.g., different species, temperature conditions, and/or management strategies).

Feed requirements predicted by the BE model for the SD1-F and SD2-F treatments were 1118.8 and 5051.6 kg ha^{-1}, respectively. Although gross yields for the SD2-F treatment were about twice as high as those for the SD1-F treatment, local feed costs will determine whether use of the higher SD is economically superior. These types of comparative analyses will be of considerable use to aquaculture planners and managers.

It is important to note that the conclusions reached in the above discussion are valid only for conditions in which feed is added after the CFB is reached, and where natural food is preferred over supplemental feed. It is possible that profiles of the natural food index different from those indicated in Figure 4 may be obtained when the fish species shows a marked preference for supplemental feed over natural food resources.

Supplemental Feeding in Unfertilized Ponds

Simulations were conducted with the BE model to examine feeding rates at MSL, 500 m, and 1000 m elevations in ponds that were not fertilized. Model assumptions were identical to those made for the comparison of fish growth in fertilized ponds at these elevations (as previously discussed), with the exception that Nile tilapia were fed to satiation from the beginning of the experiment, and the contribution of natural food resources to the diet of fish was assumed to be zero.

The BE model generated somewhat different feeding curves for the MSL, 500 m, and 1000 m sites (Figure 5). Over time, feeding rates decreased from 7.1 to 2.1% BW d^{-1} for the MSL site, from 6.6 to 1.4% BW d^{-1} for the 500 m site, and from 1.5 to 0.6% BW d^{-1} for the 1000 m site. Predicted feeding rates for the MSL and 500 m sites were within the ranges given by Hepher (1988) and Lim (1989) for tilapia. The feeding tables provided by these authors only account for differences in fish size, whereas the BE model in its simplest form generates feeding curves (Figure 5) that reflect the effects of size as well as ambient water temperature and photoperiod on appetite. Curves similar to those for Nile tilapia can be generated by applying the BE model to other species for which model parameters have been estimated. These species include channel catfish (*Ictalurus punctatus*), tambaquí (*Colossoma macropomum*), pacu (*Piaractus mesopotamicus*), and common carp (*Cyprinus carpio*). Depending on the economics of feeding and marketing, the BE model can also be used to generate different feeding curves by adjusting the target feeding level. Such curves will likely be useful for making decisions regarding the intensity of the fish culture operation.

As noted earlier, predicted fish weights obtained by use of the BE model for fed ponds (i.e., $f_n = 0$) are independent of SD. In reality, growth rates of fish stocked at high densities may be depressed due to accumulation of metabolites in the pond water or because of behavioral changes. Such behavioral changes in fish cannot be easily addressed by the use of simulation models. However, it may be possible to address the effects of water quality variables (e.g., low DO or high unionized ammonia) by linking the BE model either to time-series data for these variables or to suitable models that describe the dynamics of such variables in aquaculture ponds. Researchers in Mississippi are interested in developing and validating such models for channel catfish ponds, and collaborative opportunities will be pursued with them in the future. Until such refinements are made, stocking densities consistent with typical practices for the selected species should be used when fish growth in fed ponds is simulated with the BE model.

Feed Quality

All the simulation experiments previously described assumed that the feed quality parameter q was equal to one. To examine the effects of this parameter on fish growth and feed requirements, model experiments were conducted assuming culture conditions as described for the feed-only treatment in an experimental study conducted at El Carao (Green, 1992). Additionally, the following treatments were assumed: (i) a high quality feed (HQF; $q = 1$) expected to correspond to the pelleted ration used by Green (1992), and (ii) a low quality feed (LQF; $q = 0.8$).

For the HQF treatment, predicted fish weights and feed requirements were 266.7 g and 9612 kg ha^{-1}, respectively. Corresponding experimental results reported by Green (1992) were 262.3 g and 8971 kg ha^{-1}. Although predicted and observed fish weights were very similar, the predicted feed quantities were somewhat higher than the reported values perhaps due to differences between the fish biomass calculated from the BE model during the simulation run compared to the biomass estimated by Green (1992) on the basis of routine samplings. For the LQF treatment, predicted fish weights and feed requirements were 140.0 g and 6691 kg ha^{-1}, respectively.

These results indicate that the use of a lower value for q will lead to depressed fish growth rates, as might be expected with feeds of lower quality. If results from actual experimental trials using different feed types are available, the appropriate value of q to be used in the BE model could be determined by calibration. Such values can then be used in comparative analyses to gauge the economic benefits of using feeds of various qualities in pond aquaculture.

Model Verifications

Analysis of Fish-plankton Relationships

Past PD/A CRSP research has predominantly emphasized fertilization practices, although a few studies on supplementary feeding, stocking, and polyculture practices have been conducted. The development of guidelines to better manage fertilizer, feed, and stocking/harvest practices can be enhanced through an increased understanding of pond ecology via tools such as systems models. Such models provide a mechanism for rigid definition of relationships among system components and enable hypothesis testing in a manner analogous to physical experiments.

A variety of time-series data (e.g., size- and/or type-classified phytoplankton and zooplankton biomasses) are required to parameterize and validate systems models in POND©. Unfortunately, such data are typically not collected during CRSP experiments. Further, data that we collected from non-CRSP researchers lacked both data types and desired resolution. Nonetheless, we conducted a set of numerical experiments to verify whether some of the more complex POND© models generated results that are consistent with observations that have been made for actual ponds.

As previously documented (Nath et al., 1995), models in POND© are organized on the basis of increasing complexity into three hierarchical levels (Levels 1, 2, and 3). The Level 2 models in POND© were used in this study to explore the relationship between Nile tilapia and its natural food resources in ponds. These resources were assumed to comprise two phytoplankton pools (pool A and B), and one pool each of zooplankton and bacteria. Changes in the former three resources were described by differential equations that account for a variety of losses and gains, whereas bacterial concentrations were assumed to be constant. Fish consumption of these resources was described by the resource substitution function (Tilman, 1982; see also Bolte et al., 1995). Phytoplankton pool A was assumed to be preferred over pool B. Three SDs of Nile tilapia (1, 2, and 3 fish m^{-2}) were used in the simulation experiments.

Final predicted fish weights were 191.9, 136.1, and 106.8 g for ponds stocked at 1, 2 and 3 fish m^{-2}. Weights predicted for the lowest SD compared favorably with observed harvest weights of 189.7 g (Diana et al., 1990); at the other two densities, predicted weights exceeded observed weights by about 20 g. Although zooplankton biomass was similar for all three treatments, the biomass of the two phytoplankton pools differed substantially among the treatments (Figures 6-8). At the lowest SD, phytoplankton pool A increased slightly at the beginning of the simulation and then began to decline after about 40 d (Figure 6). Phytoplankton pool B, however, increased over time. At the intermediate SD, the decline in pool A was more rapid, and pool B after an initial increase remained more or less constant (Figure 7). Finally, at the highest SD, the biomass of pool A dropped sharply before reaching steady-state conditions (Figure 8). At this SD, pool B increased slightly at the beginning of the simulation, and then began to decline gradually. These results were presumably due to increased grazing pressure in simulated ponds with a high fish biomass, and also because the overall phytoplankton biomass was divided into two pools for which tilapia were assumed to have different preferences. The predicted changes in overall phytoplankton biomass obtained by the use of Level 2 models in POND© are consistent with the observations of Colman and Edwards (1987) for Nile tilapia stocked at different densities in tanks treated with septage. Further refinements of the more complex POND© models are planned during the next phase of OSU-DAST activities. These refinements should be of use in examining inter-relationships among natural and supplemental

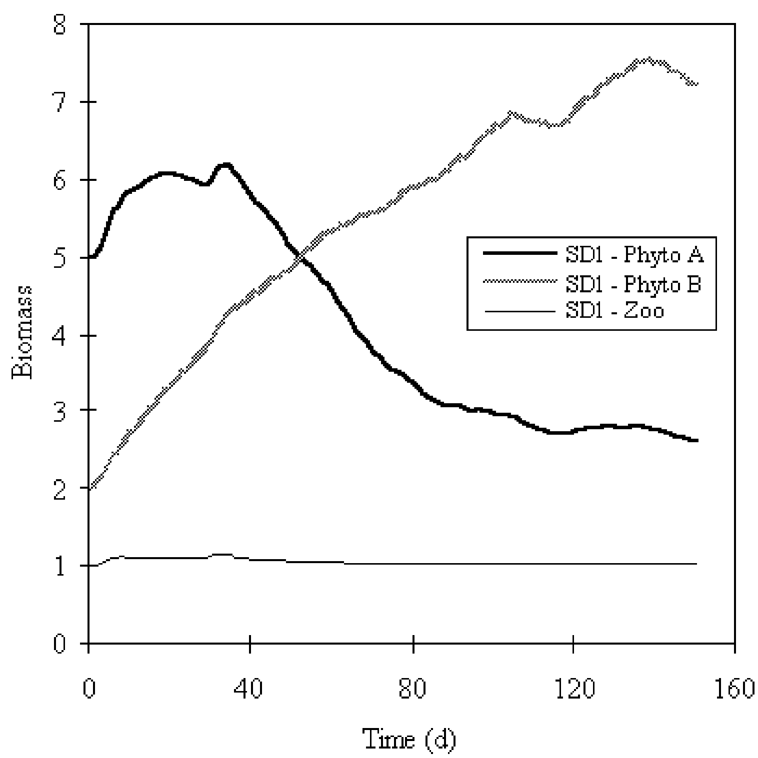

Figure 6. Biomass of the two pools of phytoplankton (in g C m^{-3}) and that of zooplankton (g m^{-1}) predicted by Level 2 models in Nile tilapia ponds stocked at 1 fish m^{-2}.

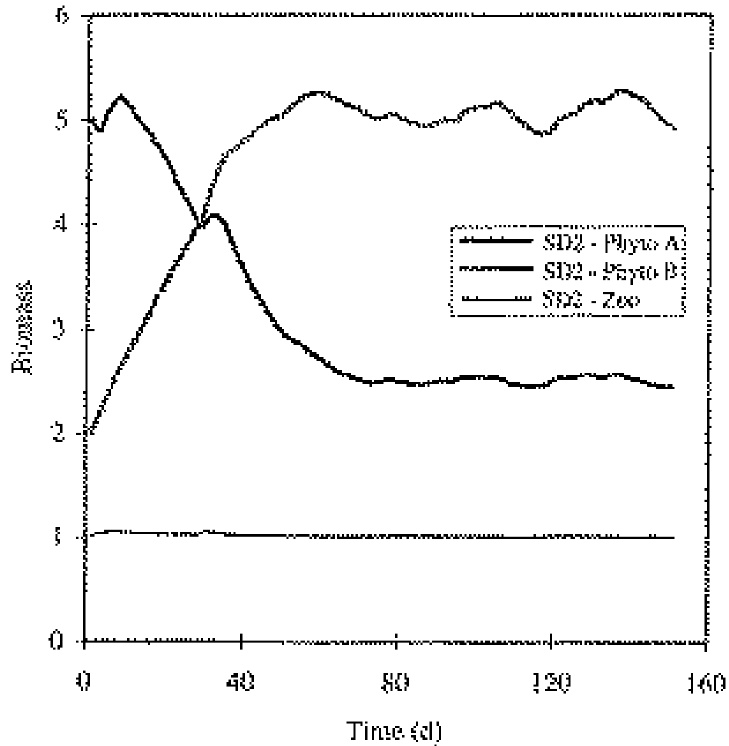

Figure 7. Biomass of the two pools of phytoplankton (in g C m^{-3}) and that of zooplankton (g m^{-1}) predicted by Level 2 models in Nile tilapia ponds stocked at 2 fish m^{-2}.

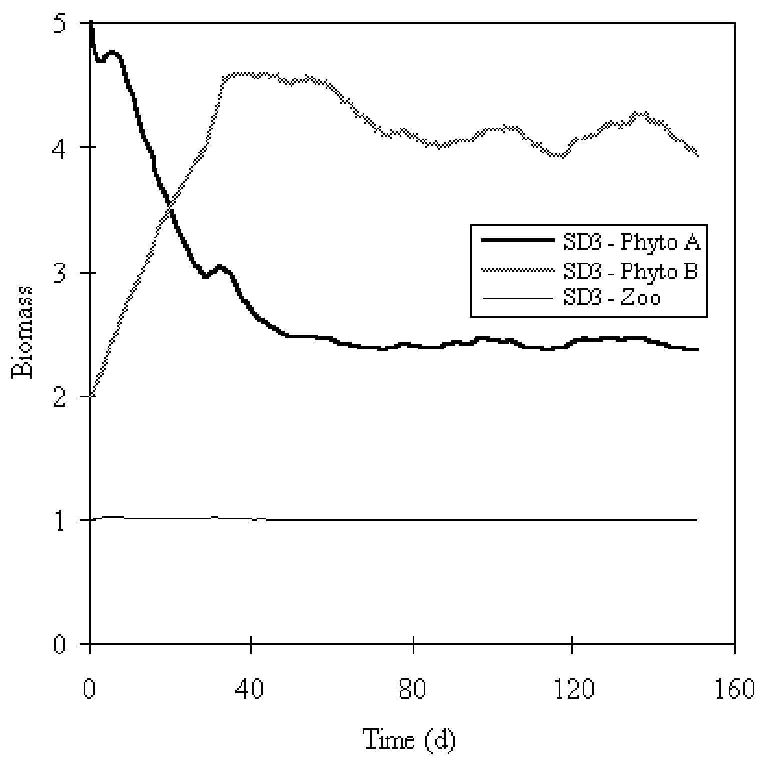

Figure 8. Biomass of the two pools of phytoplankton (in g C m^{-3}) and that of zooplankton (g m^{-1}) predicted by Level 2 models in Nile tilapia ponds stocked at 3 fish m^{-2}.

food resources and among fish species feeding from different trophic niches in polyculture ponds.

Sensitivity Analyses

It is often desirable to know model sensitivity to input data. Such sensitivity analyses are useful to assess and modify data collection protocols and often lead to improvements in model structure and predictive capabilities. Results of sensitivity analyses conducted for the water temperature and fish bioenergetics models in POND© are discussed below.

Water Temperature Model

The POND© water temperature model was subjected to a generalized sensitivity analysis with regard to input weather data, particularly because water temperature profiles are sensitive to these variables. This analysis was accomplished for both daily and diurnal simulations by a ± 10% adjustment in the values of the recorded weather data. Simulation results from these multiple runs were compared to model output (referred to as the base runs) generated by the use of the original weather dataset. Sensitivity analysis was performed for two CRSP sites (Bang Sai and AIT), where more or less complete weather records were available.

For all the sensitivity analysis scenarios described above, absolute changes in model output were summarized in terms of the average shift in water temperature with respect to the change in each of the input (I) weather variables (i.e., DT/DI). Dimensions of the weather variables were chosen to enable easy interpretation of the results. Thus, instead of expressing DT for a 10% change in air temperature, sensitivity analysis results were summarized in terms of DT for a one degree change in air temperature. Finally, in order to rank the weather variables on the basis of the magnitude of their

Table 2. Relative (RS) and absolute (AS) sensitivities of water temperature model output to a ± 10% change in the values of input weather variables for daily and diurnal simulations. The units for AS with regard to air temperature (T_a), relative humidity (R_h), short-wave solar radiation (f_{sn}), cloud cover (C_c) and wind speed (u_2) respectively are: °C/°C, °C/%, °C/MJ m^{-2} d^{-1}, °C/tenth, and °C/m s^{-1}. Negative values indicate that water temperature decreases with an increase in the value of the weather variable.

Simulation Type	Bang Sai		AIT	
	RS	*AS*	*RS*	*AS*
DAILY				
T_a	0.959	0.942	0.788	0.855
R_h	0.210	0.080	0.204	0.084
f_{sn}	0.091	0.308	0.149	0.295
C_c	0.045	0.244	0.063	0.268
u_2	-0.038	-0.701	-0.053	-1.324
DIURNAL				
T_a	0.379	0.391	0.677	0.618
R_h	0.085	0.036	0.157	0.061
f_{sn}	0.083	0.173	0.115	0.264
C_c	-0.021	-0.634	-0.036	-1.340
u_2	0.004	0.050	0.024	0.142

effects on model output, relative sensitivities (RS) were also calculated as follows:

$$RS = \frac{\left(\frac{\Delta T}{T_{mw}}\right)}{\left(\frac{\Delta I}{I_m}\right)} \quad (1)$$

where,
T_{mw} = mean water temperature (°C) for the base run; and
I_m = mean value of the weather variable in the original dataset.

Water temperatures generated from daily simulations were most sensitive to mean air temperature, followed by relative humidity, short-wave solar radiation, cloud cover, and wind speed (Table 2). This ranking of model sensitivity towards the weather variables for daily simulations was identical at both Bang Sai and AIT, although there were some differences in the magnitude of the sensitivities between the two sites (Table 2). For diurnal simulations at both sites, the ranking of model sensitivity was similar, with the exception that the sensitivity of wind speed was marginally higher than that of cloud cover (Table 2). Further, sensitivity of model output towards all the input weather variables was lower in the diurnal simulations compared to seasonal long daily simulations. Direct comparison of these two sets of simulations is, however, not strictly valid because the daily runs ignored diurnal trends and were conducted for several months, whereas the diurnal simulations lasted only 24 h.

The generally high sensitivity of model predictions to air temperature is not surprising because both seasonal and diurnal profiles of water and air temperatures in shallow static ponds are closely correlated. However, the comparatively low sensitivity of model response to changes in the short-wave solar radiation (f_{sn}) is somewhat surprising because this variable fluctuates substantially from day to day according to atmospheric conditions (Henderson-Sellers, 1984). Moreover, previously developed pond water temperature models (e.g., Fritz et al., 1980; Krant et al., 1982; Losordo, 1988) are apparently quite sensitive to f_{sn}.

Results of the sensitivity analysis in this study, however, indirectly suggest that both daily mean as well as diurnal water temperatures are closely related to evaporative heat flux, which is predominantly a function of ambient air temperature, relative humidity, and wind speed. As with assessment of pond water budgets, sensitivity analysis results suggest that weather data collection protocols for aquaculture facilities such as those established by the PD/A CRSP should include routine measurements of relative humidity in addition to variables that are already measured. It may also be useful to measure daily cloud cover if more accurate predictions of water temperature are desired.

Fish Bioenergetics Model

The bioenergetics model in POND© was subjected to a generalized sensitivity analysis with regard to the 10 model parameters (M) listed in Table 3. Sensitivity analysis was conducted only for Nile tilapia at the El Carao research station. Other model experimental conditions were as described in Teichert-Coddington et al. (1991). Sensitivity analysis was accomplished by a ± 10% adjustment in the values of the model parameters for tilapia (Table 3). Simulation results from these multiple runs were compared to model output (referred to as the base runs) generated by the use of the original parameter set.

For all the sensitivity analysis scenarios, absolute sensitivity (AS) was summarized in terms of the mean change in fish weight over the simulation period of about five months with respect to the change in each of the model parameters (i.e., DW/DM). Further, in order to rank the sensitivity of the model parameters on the basis of the magnitude of their effects on fish weights, relative sensitivities (RS) were also calculated as follows:

$$RS = \frac{\left(\frac{\Delta W}{W_m}\right)}{\left(\frac{\Delta M}{M_i}\right)} \quad (2)$$

where,
W_m = mean fish weight (g) for the base run; and
M_i = base value of the i^{th} parameter (from Table 3).

Results of the sensitivity analysis indicate that the model is extremely sensitive to the anabolism exponent parameter (*m*), followed by optimum temperature scaler (T_{opt}), food consumption

Table 3. Base values of bioenergetic parameters for Nile tilapia together with relative (RS) and absolute (AS) sensitivities of tilapia weight to a ± 10% change in the values of parameters for this species as predicted by the fish growth model. Parameters are ranked according to the magnitude of the relative sensitivities. Negative values indicate that fish weight decreases with an increase in the parameter value.

Bioenergetic Parameter	Base Value	RS	AS
Anabolism Exponent (m)	0.6277	5.3461	87.5213
Optimum Temperature Scaler (T_{opt})	32.4	-1.9374	31.7167
Food Consumption Coefficient (h)	0.4768	1.6916	27.6932
Catabolism Exponent (n)	0.8373	-1.6696	-27.3342
Efficiency of Assimilation (b)	0.7108	1.6617	27.2034
Minimum Temperature Scaler (T_{min})	18.7	-0.8272	13.5413
Minimum Catabolism Coefficient (k_{min})	0.0104	-0.4292	-7.0258
Temperature Parameter (s)	0.0288	-0.1080	-1.7674
Feeding Catabolism Coefficient (a)	0.0559	-0.0992	-1.6247
Maximum Temperature Scaler (T_{max})	39.7	0	0

coefficient (h), catabolism exponent (n), efficiency of assimilation (b), and minimum temperature scaler (T_{min}) (Table 3). It is therefore important that these parameters be estimated as accurately as possible via a combination of field experimentation (e.g., frequent sampling or estimation of food consumed) and appropriate use of POND© parameter estimation package (Bolte and Nath, 1996). The model is, however, only marginally sensitive to the other parameters (Table 3). Further, there was no response to the changes in maximum temperature scaler (T_{max}) because the effects of this parameter occur only when ambient water temperatures exceed T_{opt}, a situation that was not encountered at El Carao. Thus, the effects of parameter changes on model output are in part a function of site characteristics. For El Carao, model output was marginally sensitive to T_{min}, but the situation will likely be reversed if $T_{opt} \leq T \leq T_{max}$.

Although the BE model is substantially different from the model developed by Liu and Chang (1992) due to the higher number of variables considered, there are some similarities in the two models because they are extensions of Ursin's (1967) work. Comparison of the results of the sensitivity analyses for parameters that are common to the two models is therefore of interest. Thus, Liu and Chang (1992) reported that model output was extremely sensitive to the parameter n, with an RS of 8.80 (i.e., about five times as sensitive as the BE model's response to a change in the same parameter). It is not clear whether this is due to the additional parameters that are included in the catabolic component of the BE model or related to the different parameter values in the two models. On the other hand, the sensitivities of both models to the parameters m, h, and b are fairly comparable.

Anticipated Benefits

Model verification results presented in this report demonstrate the wide range of planning and management applications (i.e., assessment of water, fertilizer, and feed requirements) that can be addressed using the relatively simple models in POND©. Ongoing validation of the more complex models in the software has generated information on patterns of natural food consumption that is likely to be useful in further understanding fish-plankton relationships. The results obtained from both model verification exercises and sensitivity analyses should be useful in enhancing PD/A CRSP data collection protocols and designing experiments to further examine model assumptions and improve parameter estimates.

Future Directions

Although further development of POND© will involve continued model refinement, it is expected that the bulk of our efforts will focus on model verifications and applications of the software for different pond aquaculture systems. We also plan on promoting efforts for field experimentation designed to test the POND© models both within the PD/A CRSP and among other collaborators.

Literature Cited

Bolte, J.P. and S.S. Nath, 1996. Decision support for pond aquaculture: Parameter estimation for simulation models. In: H. Egna, D. Burke, M. McNamara, D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/ Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 62-67.

Bolte, J.P., S.S. Nath, and D.H. Ernst, 1995. POND: A decision support system for pond aquaculture. In: H. Egna, M. McNamara, and N. Weidner (Editors), Twelfth Annual Technical Report, Pond Dynamics Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 48-67.

Boyd, C.E., 1995. Bottom soils, sediment, and pond aquaculture. Chapman and Hall, NY, 348 pp.

Boyd, C.E., 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experimental Station, Auburn University, AL, 482 pp.

Boyd, C.E. 1982. Hydrology of small experimental ponds at Auburn, Alabama. Trans. Am. Fish. Soc., 111:638-44.

Colman, J.A. and P. Edwards, 1987. Feeding pathways and environmental constraints in waste-fed aquaculture: Balance and optimization. In: D.J.W. Moriarty and R.S.V. Pullin (Editors), Detritus and Microbial Ecology in Aquaculture. ICLARM Conference Proceedings 14, International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 240-281.

Colt, J. and D.A. Armstrong, 1981. Nitrogen toxicity to crustaceans, fish, and molluscs. Bio-Engineering symposium for fish culture, American Fisheries Society, Fish Culture Society, Publ. 1, pp. 34-47.

Emerson, K., R.C. Russo, R. Lund, and R.V. Thurston, 1975. Aqueous ammonia equilibrium calculations: Effects of pH and temperature. J. Fish. Res. Board Can., 32:2379-2388.

Eren, Y., T. Tsur, and Y. Avnimelech, 1977. Phosphorus fertilization of fishponds in the Upper Galilee. Bamidgeh, 29:87-92.

Fritz, J.J., D.D. Meredith, and A.C. Middleton, 1980. Non-steady state bulk temperature determination for stabilization ponds. Water Research, 14:413-420.

Green, B.W., 1992. Substitution of organic matter for pelleted feed in pond aquaculture. Aquaculture, 101:213-222.

Green, B.W. and C.E. Boyd, 1995. Water budgets for fish ponds in the dry tropics. Aquacultural Engineering, 14:347-56.

Green, B.W., D.R. Teichert-Coddington, and T. R. Hanson, 1994. Development of semi-intensive aquaculture technologies in Honduras. International Center for Aquaculture and Aquatic Environments, Research and Development Series No. 39, Auburn University, AL, USA, 48 pp.

Henderson-Sellers, B., 1984. Engineering limnology. Pitman Publishing Limited, London, 356 pp.

Hepher, B., 1978. Ecological aspects of warm-water fishpond management. In: S.D. Gerking (Editor), Ecology of Fresh Water Fish Production. Wiley Interscience, New York, pp. 447-468.

Hepher, B., 1988. Nutrition of Pond Fishes. Cambridge University Press, Cambridge, 388 pp.

Hopkins, K.D. and C.F. Knud-Hansen, Submitted. Comparison of three fertilization strategies: Algal assay, nutrient concentration and fixed input. Submitted to Aquaculture.

Hopkins, K.D., E. Lopez, and J.P. Szyper, 1994. Intensive fertilization of tilapia ponds in the Philippines. In: H. Egna, J. Bowman, B. Goetze, and N. Weidner (Editors), Eleventh Annual Technical Report, Pond Dynamics Aquacuture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 16-20.

Knud-Hansen, C.F. and H. Guttman, Submitted. An algal bioassay method for pond fertilization. Submitted to Aquaculture.

Krant, J., F. Motzkin, and H. Gordin, 1982. Modelling temperatures and salinities of mixed seawater fish ponds. Aquaculture, 27:377-388.

Lannan, J.E., 1993. Users guide to PONDCLASS: Guidelines for fertilizing aquaculture ponds. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, 60 pp.

Lim, C., 1989. Practical feeding–Tilapias. In: T. Lovell (Editor), Nutrition and Feeding of Fish. AVI, New York, pp. 163-183.

Liu, K.M. and W.Y.B. Chang 1992. Bioenergetic modelling of effects of fertilization, stocking density, and spawning on growth of Nile tilapia, *Oreochromis niloticus*. Aquaculture and Fisheries Management, 23:291-301.

Losordo, T.M., 1988. The characterization and modeling of thermal and oxygen stratification in aquaculture ponds. Ph.D. dissertation, University of California at Davis, 416 pp.

Nath, S.S., J.P. Bolte, and D.H. Ernst, 1995. Decision support for pond aquaculture planning and management. Presentation at Sustainable Aquaculture '95, PACON International, 11-14 June 1995, Honolulu, Hawaii.

Nath, S.S., J.P. Bolte, and D.E. Ernst, 1996. Decision support for pond aquaculture: Simulation models and applications. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 42-61.

Shreshtha, M.K. and C.K. Lin, 1996. Phosphorus fertilization strategy in fish ponds based on sediment phosphorus saturation level. Aquaculture, 142:207-219.

Szyper, J.P. and K.D. Hopkins, 1995. Management of carbon dioxide balance for stability of total alkalinity and phytoplankton stocks in fertilized fish ponds. In: H. Egna, J. Bowman, B. Goetze, and N. Weidner (Editors), Twelfth Annual Technical Report, Pond Dynamics Aquaculture CRSP, Office of International Research and Devlopment, Oregon State University, Corvallis, OR, USA, pp. 28-32.

Teichert-Coddington, D.R. and H. Ramos, 1995. Nutrient input management by the computer program, PONDCLASS, and by concentration of a key nutrient. Twelfth Annual Technical Report, Pond Dynamics Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 20-27.

Teichert-Coddington, D.R., B.W. Green, and M.I. Rodriguez, 1990. Culture of tilapia with combinations of chicken litter and a commercial diet: Water quality considerations. In: H. Egna, J. Bowman, and M. McNamara (Editors), Seventh Annual Administrative Report, Pond Dynamics Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 16-20.

Teichert-Coddington, D.R., B.W. Green, N. Claros, and M.I. Rodriguez, 1991. Optimization of feeding in combination with organic fertilization. In: H. Egna, J. Bowman, and M. McNamara (Editors), Eighth Annual Administrative Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 30-32.

Tilman, D., 1982. Resource Competition and Community Structure. Princeton University Press, Princeton, NJ, 296 pp.

Ursin, E., 1967. A mathematical model of some aspects of fish growth, respiration, and mortality. J. Fish. Res. Bd. Can., 24:2355-2453.

PD/A CRSP Central Database

Interim Work Plan, Database Management

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(Printed as Submitted)

Introduction

This document discusses the Central Database status at time of transfer to Oregon State University and the current Database status as of December 1996. Publication of the Database on the Internet and through additional collaborative efforts is also discussed. Data table formats, definitions, and guidelines for submitting new data are discussed under Central Database Organization and Guidelines for Data Submission (1996). For a comprehensive review of the mission, mechanisms, and use of the Database, see the Final Report by the Special Committee on Database Management (Batterson et al., December 1991).

Prior Status of Database

The PD/A CRSP Central Database was maintained by the Management Entity from 1985 until Spring 1993, when it was transferred to Kevin Hopkins at the University of Hawaii at Hilo. The Database was received by John Bolte (DAST PI) and Doug Ernst (Database Manager) at Oregon State University from Kevin Hopkins in May of 1996. Over the period 1985-1996, the Database migrated through a series of computer operating systems and database software. When received at OSU, the Database contained data from 82 experiments, which were completed under Work Plans 1 through 7 from 1983 to 1995. The data were organized by experiment (site and time) and by data type (e.g. weather, water, fish) into 720 separate files, maintained in dbf format using FoxPro database software.

Considerable re-organization and editing of the Database was required to implement relational data structures and provide efficient mechanisms for data access and publication. Most of these problems had been recognized by the prior Database Manager and were brought to the attention of the new Database Manager when the Database was transferred. Prior problems with the Database included:

- Lack of descriptions of experimental treatments, and thus lack of a corresponding fish production methodology context from which a Database user could identify and extract specific data;
- Lack of relational data organization, i.e. linking of associated data through common primary data;
- Existence of partially or fully duplicate records, i.e., data redundancy and conflict;
- Some lack of consistency in pond names, both within data sets of single experiments and among multiple experiments at a given site;
- Redundant and undefined names for some fish stocks and pond application materials;
- Poor organization of water quality data regarding time and depth of water samples;
- Inadequate pond area data required to interpret fish stocking numbers; and
- Incomplete data checking for reasonable range values.

In addition, the Database required better linkage to the greater PD/A CRSP literature and information base, through cross referencing and shared data files. Specific areas for improvement included:

- Information regarding principal investigators responsible for specific experimental data sets, to be used for data citations and referrals
- Site and facility descriptions and physical data, to be used in conjunction with experiment treatment specifications
- References to PD/A CRSP literature (Work Plans, Technical Reports, Annual Reports, etc.) and other external publications, to be used to augment experiment treatment descriptions, provide research objectives and context, and provide experimental results and discussions.

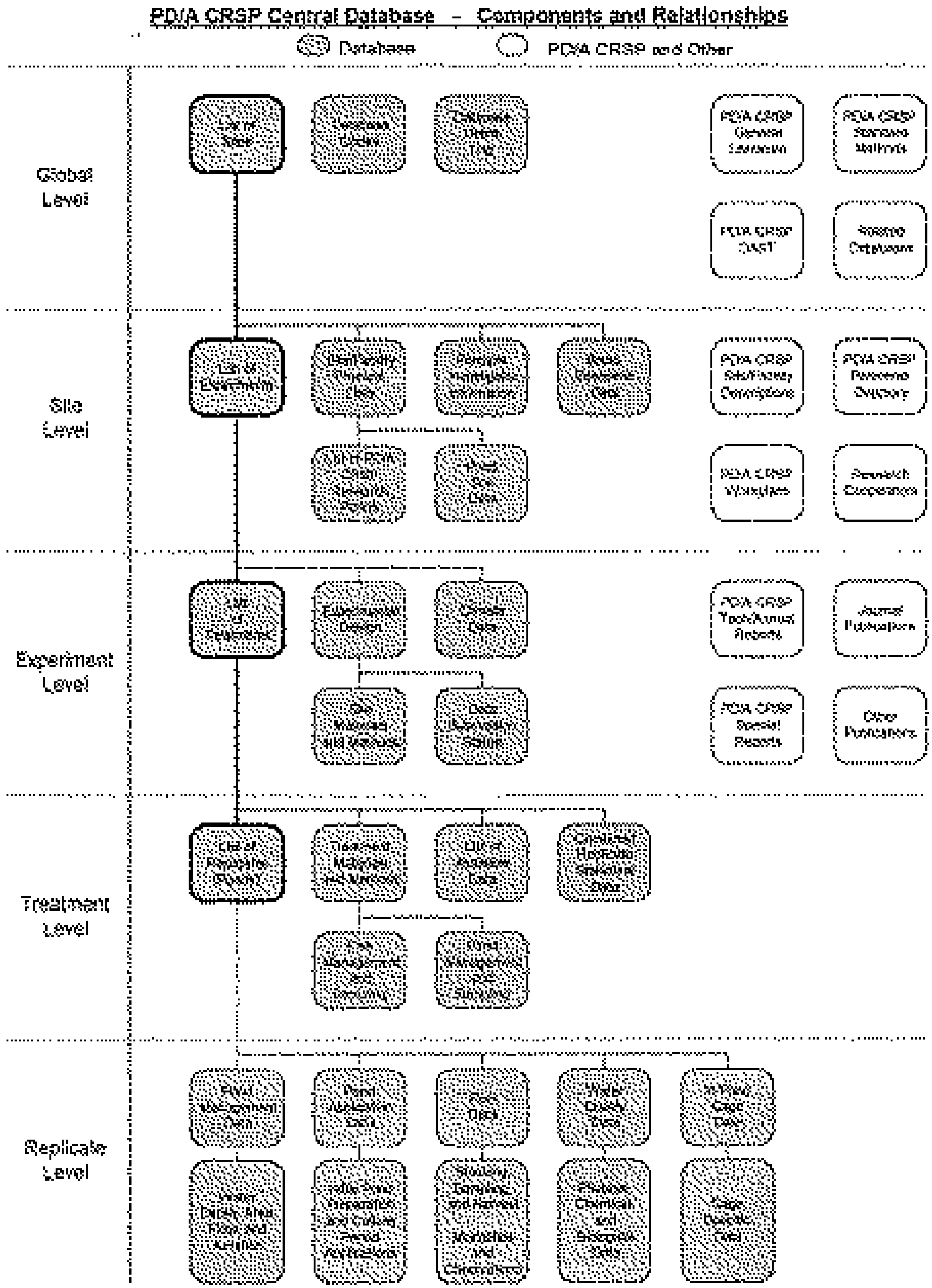

Figure 1. PD/A CRSP Central Database—Components and Relationships.

Current Status of Central Database

The Database is now managed under Microsoft Access and consists of one computer file (crsp.mdb, approx. 60 MB) containing multiple data tables (Figure 1; also see Central Database Organization and Guidelines for Data Submission). Data tables are made up of *records* (rows) and *fields* (columns) of data cells, analogous to a computerized spreadsheet. These data tables are related through *relational rules* and *primary keys* that, together with data field rules, prevent entry of incompletely defined, duplicate, or conflicting data. A list of all experiments currently in the Database is given in Table 1.

While efforts to solve problems with the Database continue, major problems have been eliminated. Through the use of data submission and data entry protocols, past problems will not be allowed to redevelop. New data submissions for the Database will not be accepted until experimental treatments are defined. Efforts that continue to better define experimental treatments include site and personnel information, and references to PD/A CRSP and other publications. Missing experiments from past Work Plans and the status of data submission from the current Work Plan remain to be determined. Investigators are encouraged to review the Database experiment list (Table 1) and see that all

Table 1. List of experiments in PD/A CRSP Central Database (total 82).

Site Name	Site Country	WP	Exp	Date Start	Date End
Abbassa	Egypt	07	1A	6/30/93	11/25/93
Aguadulce	Panama	01	01	2/6/84	5/18/84
Aguadulce	Panama	01	02	7/26/83	12/13/83
Aguadulce	Panama	02	01	1/30/85	5/3/85
Aguadulce	Panama	02	02	7/19/84	12/19/84
Aguadulce	Panama	03	01	3/18/86	5/30/86
Aguadulce	Panama	03	02	7/14/86	11/23/86
AIT	Thailand	04	02	3/8/88	9/20/88
AIT	Thailand	04	05	5/16/88	10/12/88
AIT	Thailand	04	06	12/20/88	5/22/89
AIT	Thailand	05	05	9/29/89	3/22/90
AIT	Thailand	05	09	12/4/91	5/6/92
AIT	Thailand	05	10	11/26/90	4/25/91
AIT	Thailand	06	01	9/10/92	1/8/93
AIT	Thailand	06	03	5/30/91	10/31/91
AIT	Thailand	06	04	12/6/91	7/2/92
AIT	Thailand	07	03	9/15/93	12/14/93
AIT	Thailand	07	05	12/1/94	5/4/95
AIT	Thailand	07	06	1/21/94	6/21/94
Ayutthaya	Thailand	01	02	8/1/84	1/4/85
Ayutthaya	Thailand	02	01	2/1/85	6/29/85
Ayutthaya	Thailand	02	02	8/3/85	12/27/85
Ayutthaya	Thailand	03	01	2/7/86	7/7/86
Ayutthaya	Thailand	03	02	8/6/86	12/29/86
Ayutthaya	Thailand	04	01	2/2/87	7/1/87
Ayutthaya	Thailand	04	03	2/5/88	6/7/88
Ayutthaya	Thailand	04	04	10/7/88	3/7/89
Ayutthaya	Thailand	05	02	10/12/89	3/8/90
Ayutthaya	Thailand	05	03	5/10/91	9/9/91
Ayutthaya	Thailand	05	04	10/25/90	3/21/91
Ayutthaya	Thailand	05	08	10/9/91	3/19/92
Ayutthaya	Thailand	06	05	6/11/92	11/13/92
Ayutthaya	Thailand	06	06	11/11/93	7/20/94
Ayutthaya	Thailand	06	07	1/21/93	12/9/93

data are submitted through Work Plan Seven (Sept. 1, 1993 to Aug. 31, 1995). Also remaining to be accomplished is determination of the completeness of the data that have been submitted and notification to investigators regarding conflicting data that have been deleted by the Database Manager.

It is important to realize that the pond-specific fish performance and water quality data contained in the Database is relatively meaningless without knowledge of how the ponds were managed (i.e., experimental treatments). It is also useful to know how ponds were organized regarding experiment-treatment-replicate hierarchies. There was some use of pond treatment codes in the Database, but these treatment codes were only partially used and defined. The PD/A CRSP Work Plans and Technical/Annual Reports were of limited use for defining treatment specifications in the Database, especially after Work Plan 3, given their superset relationship to the Database subset and lack of linking references.

To generate experiment treatment specifications to the best degree possible, a multistage procedure is being used: 1) compile all existing treatment data (Database and PD/A CRSP literature); 2) compile all fish stocking and pond application data in the Database and summarize as rate values; 3) develop a table of pond specific treatment specifications; and 4) have investigators review treatment specifications for completeness and accuracy. For development of fish stocking and pond application treatment specifications from the Database, the Database was first searched to find all ponds (sometimes cages) associated with each experiment and then searched to compile all fish stocking and material application data for each pond that was found. This treatment data (Database table ExpTreat) currently shows a grand total of 1311 replicates for the 82 experiments currently in the Database, with an approximate average of four treatments per experiment and four replicates per treatment. Of these 1311 replicates, it was found that a total of 226 had no fish stocked, and a total of 355 had

Table 1. Continued.

Site Name	Site Country	WP	Exp	Date Start	Date End
Ayutthaya	Thailand	06	6R	1/26/94	3/23/95
Ayutthaya	Thailand	07	6R	11/16/94	4/19/95
Bogor	Indonesia	01	01	6/19/84	11/12/84
Bogor	Indonesia	01	02	10/31/83	3/20/84
Bogor	Indonesia	02	02	1/10/85	6/10/85
Bogor	Indonesia	03	01	4/9/86	9/12/86
Bogor	Indonesia	03	02	10/14/86	3/12/87
Butare	Rwanda	01	01	2/26/86	7/22/86
Butare	Rwanda	01	02	10/1/86	2/26/87
Butare	Rwanda	03	01	7/9/86	12/4/86
Butare	Rwanda	03	02	12/18/85	5/15/86
Butare	Rwanda	04	01	1/1/99	1/1/70
Butare	Rwanda	04	02	6/23/88	12/8/88
Butare	Rwanda	04	03	5/5/89	9/28/89
Butare	Rwanda	04	04	12/29/88	3/30/89
Butare	Rwanda	05	01	10/30/89	3/20/90
Butare	Rwanda	05	03	7/31/90	1/31/91
Butare	Rwanda	05	07	8/24/91	1/3/92
Comayaga	Honduras	01	01	1/12/84	6/12/84
Comayaga	Honduras	01	02	7/11/84	12/10/84
Comayaga	Honduras	02	01	1/16/85	6/15/85
Comayaga	Honduras	02	02	7/26/85	12/23/85
Comayaga	Honduras	03	01	2/7/87	7/8/87
Comayaga	Honduras	03	02	6/5/86	11/5/86

no applications of feed or fertilizer. Whether these results represent actual pond management or data errors/omissions needs to be determined. It was also found that pond areas required to convert total fish stocking numbers to fish per unit area were inadequately reported (Database table PondSpecs). Investigators are asked to submit any past pond depth-area data not submitted to the Central Database and to bring all pond depth-area data up to date with new submissions to the Central Database.

The need to add data tables for sociological and economic data is recognized. Appropriate investigators will be contacted to determine what this socio-economic data would consist of and what is currently available. Collaboration will also be sought with the PD/A CRSP Management Entity to coordinate and standardize data management regarding aquaculture research sites and facilities, technical and annual report references, external publication references, and investigator references. Hopefully, a Database user can easily determine all associated publications (CRSP and external) of a given data subset at the time the data are queried. Investigator reference data are required to properly cite data subsets and to provide contact information to interested Database users, analogous to the information given in journal articles.

Central Database Publication

A user and investigator interface to the Central Database is now provided at the designated Internet Web site of the Database (http:// biosys.bre.orst.edu/crspDB/). This Database interface utilizes Cold Fusion software under a Windows NT operating environment. Tabular data presentation is available and graphical data presentation is under development. A log maintained at the Web site is used to document Database users, including optional contact

Table 1. Continued.

Site Name	Site Country	WP	Exp	Date Start	Date End
Comayaga	Honduras	04	01	8/11/88	12/20/88
Comayaga	Honduras	04	02	2/3/89	7/3/89
Comayaga	Honduras	05	01	7/27/89	12/21/89
Comayaga	Honduras	05	02	2/13/90	6/19/90
Comayaga	Honduras	05	05	8/8/90	1/3/91
Comayaga	Honduras	05	06	2/26/91	7/30/91
Comayaga	Honduras	06	01	9/5/91	2/4/92
FAC	Philippines	06	10	11/15/91	4/15/92
FAC	Philippines	06	11	7/1/92	11/4/92
FAC	Philippines	06	12	1/7/93	5/9/93
FAC	Philippines	07	09	5/31/94	10/15/94
FAC	Philippines	07	11	7/21/93	11/22/93
FAC	Philippines	07	13	11/22/94	4/24/95
Gualaca	Panama	01	01	2/15/85	5/21/85
Gualaca	Panama	01	02	7/8/85	12/2/85
Gualaca	Panama	03	01	1/27/86	6/25/86
Gualaca	Panama	03	02	7/21/86	12/9/86
Iloilo	Philippines	01	01	2/1/84	7/3/84
Iloilo	Philippines	01	02	7/11/83	12/12/83
Iloilo	Philippines	02	01	11/24/84	5/7/85
Iloilo	Philippines	02	02	8/16/85	2/28/86
Iloilo	Philippines	03	01	3/17/86	7/24/86
Iloilo	Philippines	03	02	9/3/86	11/13/86
Nong Sua	Thailand	01	01	1/1/99	1/1/70

information, objectives in data use, and comments on data use. The Database Web site is linked to the PD/A CRSP Web Site and to other aquaculture-related web sites. For intensive users of the Database, the entire Database could also be made available on electronic media, e.g., CD or 100 MB Zip Disk, given access to required hardware at the Database and user sites.

In the past, the Central Database has served mainly as a data repository with relatively few requests for data (about 30) as of December 1996. This lack of use by the aquaculture community was likely due to a combination of factors, including lack of awareness, difficulties in Database access, and lack of the necessary Database infrastructure to facilitate the search and extraction of specific data. Certainly, the Database problems itemized above would have been a major hindrance to anyone using the Database. If these assumptions are true, then publication of the Database at a Web site with a user-oriented interface should show clear improvement in the utilization of the Database. It may also be necessary, however, to better advertise the Database Web site beyond the PD/A CRSP community. A particularly under-utilized and promising audience is the aquaculture education community.

In addition to the Database Web site, the Database will be available at a world-wide environmental data Web site maintained by the Consortium of International Earth Science Information Network (CIESIN). Inclusion of some areas of the Database in FISHBASE, maintained by ICLARM/FAO, is being investigated. Potential collaboration with the aquaculture database maintained by the Network of Aquaculture Centers in Asia Pacific (NACA) will also be investigated. Other related databases, such as the Tropsoils CRSP database and the SADC Small Water Body database, will be contacted for the purpose of establishing a network of aquatic related databases and globally standardized data reporting.

The data search strategy supported by the Database Web site interface is based on a site, time, production-methods approach for defining and extracting data subsets. In this context, the “experimental treatment protocols” of investigators are analogous to the “fish production methods” of fish culturists. The components of this methods-based database query include 1) experimental site; 2) inclusive dates; 3) fish/shrimp species; 4) fish/shrimp stocking density (fish/m^2) and existence of polyculture; 5) initial fish/shrimp size (g); and 6) pond application fertilizers and feeds, including application frequency (days) and rates (kg/ha/wk).

These management components may be specified and applied in any order, whereby a single set of specifications, or through a series of iterative refinements, a user can define and extract a given subset of data. Investigators may go directly to a specific study by simply specifying site name and inclusive dates.

This approach to data queries provides the Database user with the ability to extract and compare any combination of fish production treatments. This ability is a unique characteristic of the PD/A CRSP research effort, with great potential for leveraging the usefulness of this data beyond report and journal publication. Further work is required to provide statistical tools for the user, including statistical summaries (e.g. minimum-maximum, mean, and standard deviation) and treatment comparisons (e.g. analysis of variance).

Principal investigator reference information is considered critical to properly acknowledge data subsets extracted from the Database. Data citations will appear automatically as users extract specific data sets, with the following format:

> Pond Dynamics/Aquaculture Collaborative Research Support Program Central Database, (Diskette or Internet). (Inclusive dates of data used). Bioresource Engineering Dept., Oregon State University, Corvallis, OR USA. Available: Research country and site, principal investigator(s), inclusive dates of data used.

It is hoped that publication of data in the Database will be held in the same regard as its publication in reports and journals, and that equal incentives for investigators will apply. Publication of data in the Database should be viewed as an opportunity for additional research outreach, impact, and recognition.

Doing Development by Growing Fish: A Cross-National Analysis of Tilapia Harvest and Marketing Practices

Interim Work Plan, Socioeconomic Study

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Introduction

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has been organized to generate basic science that may be used to advance aquacultural development. The research network has focused on tilapia (*Oreochromis niloticus*), sometimes called "the aquatic chicken." Tilapia is an export commodity generating foreign exchange as well as a subsistence crop for other parts of the farm sector. Farm ponds provide food security, nutrition, and occasional cash income for the rural poor (Castillo et al., 1992; Lightfoot et al., 1991). This paper examines the primary methods of fish harvesting and marketing tilapia in four CRSP countries. Practices and perception related to marketing tilapia are summarized across the research sites.

Aquaculture as a Development Intervention

Fish farming is undertaken as a development intervention for manifold reasons. On one level, fish farming can increase the supply of fish for urban and rural consumers thereby enhancing the quality and quantity of the food supply. At the village level, fish farmers and their families can benefit from improved food security, diet variety, protein availability, and cash income from fish sales.

The tilapia enterprise plays a diverse set of roles in farm and family systems. The identity of fish culture is contingent on the needs of the family and the resources—land, labor, and capital—that can be applied to the activity (Pollnac, 1992). In some cases, industrial scale tilapia farms play a significant role in industry development by providing fingerlings, processing facilities, and a corporate voice in national aquacultural policy. This analysis focuses on medium- and small-scale family farms where fish farming can make the most immediate contribution to family well-being (Cernea, 1991a; 1991b).

Sustainability

Sustainability is the ultimate measure of success for a development intervention (Molnar et al., 1991). If people continue to grow fish while being emulated by their neighbors and residents of other communities, aquaculture will have furthered the cause of development and food security (Molnar and Duncan, 1989). Sustainability has environmental, social, and institutional dimensions (Ben-Yami, 1986; Coughenour, 1992; McCorkle, 1989).

Aquaculture is socially sustainable when neither its benefits nor its costs are concentrated in one segment of the population while having at least some direct impact on those most in need. Ideally, fish farming should engender equitable participation in its benefits across a wide spectrum of socioeconomic segments of the community. In reality, not all farmers are inclined or able to build ponds (Molnar et al., 1985). Aquaculture must be economically viable for those who do undertake the activity if the enterprise is to realize the promise of income improvement and a wider distribution of benefits (Hatch et al., 1995).

Other constraints limit participation in aquaculture to those able to make productive use of their time and resources in the activity. A small number of landless poor may benefit from wage labor on larger operations. Nevertheless, fish farming can improve the array of locally based opportunities for food production and income generation that benefits many residents in different ways (Smith and Peterson, 1982).

The social costs of aquaculture are often connected to conflicts linked to the loss of access to resources (Bailey et al., 1996). Fish farming may accelerate the enclosure of formerly open access lands or coastal waters. Private fish ponds may divert water from formerly shared uses; effluent from ponds may alter the quality of water for other users. When the expansion of aquaculture limits opportunities or livelihoods for other community residents, social sustainability may be questioned. Aquaculture is institutionally sustainable when the services and subsidies required to build and continue the industry do not exceed the fiscal capacity of the state. Ultimately, sustainability is achieved when subsidies cease and state services become minimally necessary to aquaculture's viability as a widely practiced farm enterprise. It should be noted that the primary influence of PD/A CRSP activities is exerted through the institutional context of the research sites and the network of students, extensionists, technicians, and host country scientists that collaborate with PD/A CRSP scientists.

Livelihood activities such as aquaculture are embedded in a structure of social relations—among farmers as well as between farmers and larger systems. Harrison (1995) found that one of the principal constraints faced by nonadopters of aquaculture in Zambia was security of land tenure, a constraint felt most forcefully by women. Rothe and his colleagues (1992) concluded that tenure security was necessary but not sufficient for the adoption of productivity-enhancing technology in agriculture. As long as constraints on access to input and output markets limit incentives to innovate and invest, tenure security itself does not represent a binding constraint on technology adoption. Because pond construction represents direct capital investment in the land, tenure security may be the larger factor in farmer decisions than other kinds of productivity-enhancing technology.

Access to labor for pond construction was a primary barrier to participation in aquaculture for women in Zambia (Harrison, 1995; 1991). Engle (1987) reviewed the role of women in aquacultural training and extension. In Rwanda, women were consistently more likely to cite role conflicts or hardships associated with fish culture as an addition to their repertoire of activities (Molnar et al., 1994). Responsibilities and burdens of feeding, monitoring, harvesting, and preparing the fish may not coincide with the nutrition, cash, and other benefits accruing to fish harvests and marketing.

Materials and Methods

A sample of tilapia farmers was interviewed in each of four PD/A CRSP countries; Rwanda, Honduras, Thailand, and the Philippines. The following sections detail the procedures employed in each locale and the approach used to analyze the data (Molnar et al., 1996).

Rwanda

Data were obtained from a sample of 121 active Rwandan fish farmers in eight local administrative districts (communes) during the Winter of 1991 and early Spring of 1992.[1] The interview schedule used in Rwanda in 1992 was revised and adapted for each of the three PD/A CRSP countries surveyed in 1993-95.

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[1] The 141 *communes* (or counties) are the basic units of administration in Rwanda. Several communes were chosen to represent diversity in the nation's regions; others were selected randomly. Interviews were conducted with 115 active fish farmers randomly selected from National Fish Culture Service (SPN) extension rolls. About 45 percent of the respondents were women. To contact respondents, aquaculture *monitors* (extension representatives) were asked to organize meeting points and times with the farmers and the interviewer. The Rwandan interviewer conducted individual interviews in the native *Kinyarwanda* language using a standardized set of questions and response frameworks. Approximately 60 minutes were spent with each farmer. An additional 16 active farmers who had not received extension assistance were interviewed. These emulator farmers had independently adopted fish culture as a farm enterprise. They were selected in a two-step process. First, fish farmers in areas not receiving extension assistance were identified through network sampling procedures and local informants (Casley and Kumar, 1988). General agricultural extension agents then provided information about individuals who had constructed fish ponds. Local residents also made referrals to farmers who had ponds, and neighbors provided information about the owners of ponds visible from the roadside.

Honduras

Data were obtained from a sample of 51 active Honduran fish farmers in nine of 15 Honduras departments during Fall, 1993. The survey instrument was translated and all interviews were conducted in Spanish. Tilapia farmers were identified through referrals made by Peace Corps volunteers working in fish culture, Honduran extension personnel, and by farmers identifying neighbors raising tilapia. The departments were chosen to represent the major tilapia production regions in the country.

Philippines

Data were obtained from a sample of Philippine fish farmers in four of 15 provinces on the main island of Luzon during Winter of 1994. Tilapia farm operators in Bulacan, Nueva Ecija, Pampanga, and Tarlac provinces were interviewed. The survey was revised and adapted, then translated into the Tagalog language. Tilapia farmers were identified by sampling lists of farmers purchasing fingerlings at the Freshwater Aquaculture Center at Central Luzon State University in Muñoz. Sample farmers were asked to identify neighbors raising tilapia who also were approached for interviews. The provinces were chosen to represent the major tilapia production region in the country. Interviews were conducted with 51 active fish farmers.

Thailand

Data were obtained from a sample of 51 active Thai fish farmers in three of 75 Thai provinces during Winter, 1994. Tilapia farm operators in Ayutthaya, Pathum Thani, and Nakhom Pathom provinces in Central Thailand were interviewed. The survey was revised and adapted, then translated into the Thai language. All interviews were conducted in Thai. Tilapia farmers were identified through referrals made by Department of Fisheries extension personnel, knowledgeable local individuals, and by fish farmers giving identifying neighbors raising tilapia. The provinces were chosen to represent major tilapia production regions in south Central Thailand, the major aquaculture region in the country.

Analysis

In each country, the interview schedules were edited to reconcile missing data, ambiguous answers, and exceptional cases[2]. The data were keypunched according to precoded numerical response categories on the printed questionnaire that did not require translation. Open-ended questions eliciting responses that were transcribed verbatim were cumulated in a separate process (Casley and Kumar, 1988).[3] The tables tabulate survey responses by farm size expressed in terms of pond area operated.

Farm pond area, as a measure of farm size, is expressed in three categories—small, medium, and large. The category boundaries vary depending on the range reported in the surveys for each country.[4] These categories correspond well with production intensity levels and allow cross-country and intra-country pond area comparisons. Pond area has a close correspondence to subsistence, small-scale, and commercial levels of aquaculture production (Hatch and Hanson, 1991). Rwanda

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[2] The 1992 Rwanda sample is more representative than the samples drawn in the other countries. It is nationwide, a larger number of interviews was obtained, and the range of variability in the population of fish farmers is smaller in Rwanda. In Rwanda, the 121 farmers in the sample represent 3.9 percent of the 3,102 (1,950 group and 1,152 individual) ponds in the country in 1990. Women are 24 percent of the fish farmers in Rwanda and 43 percent of the sample (Moehl and Molnar, 1995). Women were oversampled in the 1992 study. Molnar et al. (1993) previously examined the Rwanda data in detail, but the aggregate findings are presented here to allow comparative analysis across four PD/A CRSP sites.

[3] Certain cautions are in order. There are limits to the ability of these data to extrapolate to wider populations of fish farmers and other regions of the selected nations. In comparison to Rwanda, the 1993 samples in Thailand and the Philippines are smaller and represent a subset of provinces in one key production area in the country. In Honduras, the sample is drawn from a diverse set of locales across the tilapia producing areas of the country. The number of farmers in each sample are inadequate for statistical estimation of population parameters; they do, however, provide information about practicing fish farmers where none is otherwise available.

[4] The small pond area grouping is less than or equal to 0.11, 0.65, and 0.96 hectares in Honduras, the Philippines, and Thailand. The medium pond-area groupings in Honduras, the Philippines, and Thailand are 0.12 to 0.65, 0.66 to 3.0, and 0.97 to 1.76 hectares, respectively. The large pond area groupings are greater than 0.65, 3.0, and 1.76 hectares in Honduras, the Philippines, and Thailand, respectively.

Table 1. Production cycle length, crops per year, average harvest weight, and harvest strategy according to pond area in the Philippines, Honduras, and Thailand, 1994.

Country and Size Category	Production Cycle	Tilapia Crops Per Year			Average Harvested	Harvesting Strategy[1]		
	No. of Days	*One (%)*	*Two (%)*	*Three (%)*	*Fish Weight (g)*	*Partial (%)*	*Partial+1 (%)*	*Single (%)*
PHILIPPINES								
Small	145	39	61	0	173	80	13	7
Medium	149	21	68	11	199	74	16	11
Large	139	13	69	19	179	50	36	14
HONDURAS								
Small	194	41	53	6	274	24	35	41
Medium	263	67	27	7	275	33	13	53
Large	235	53	40	7	570	47	20	33
THAILAND								
Small	307	83	17	0	328	0	13	87
Medium	346	100	0	0	301	0	15	85
Large	358	100	0	0	411	12	24	65

[1] Harvest strategies include: Partial—partial-harvesting; Partial+1—partial-harvesting and one large harvest at end of the cycle; Single—one large harvest at the end of the cycle and no partial-harvesting.

data were reported in the “small” pond area category because of the country’s homogeneous low-intensity type of tilapia production, regardless of actual pond area. Perceptions of marketing problems and constraints were aggregated across size categories.

Results

Production Cycle Characteristics

Length of the tilapia production cycle, harvesting strategy, and sizes of final product within the surveyed CRSP countries were indicators of production cycle characteristics and market demands (Table 1). Production cycles were the shortest in the Philippines, ranging from 139 to 149 days, and two crops per year were usually produced. However, the fish produced were smaller, ranging from 173 to 199 grams, than in the other two countries. These data were not obtained in Rwanda.

Growing small fish is an ideal production strategy if the consumer will accept a tilapia in the 100 to 200 gram range. It is much more efficient to produce large numbers of small fish than it is to produce the same number of larger fish. Honduran farmers had production cycles ranging from 194 to 263 days and one to two crops per year (Table 2). The average fish produced ranged from 274 to 570 grams. In this country, partial harvesting, partial harvesting along with one large harvest, and one harvest only were used.

Thailand had the longest production cycle of the three countries. It ranged from 307 to 358 days (Table 1). The longer cycles resulted in larger fish for the small and large farms. Medium area farms had intermediate values when culture period and fish size were compared.

One large harvest by pond draining at the end of the culture period was the most frequent approach. Less partial-harvesting was used in Thailand, where one large harvest at the end of the production cycle was preferred by nearly all respondents.

Relative Prices of Fish

Prices received for tilapia are related to the final size of the fish, consumer size preference, and available market outlets. In this survey, the prices for tilapia were lowest in Thailand and comparable in the Philippines and Honduras (Table 2).

Table 2. Average price and range of prices received for tilapia in the Philippines, Honduras, and Thailand, 1993-1994.

Country and Pond Area	Average Price Received ($/kg)	Range of Prices Received ($/kg)
PHILIPPINES		
Small	1.70	0.97 - 2.34
Medium	1.86	1.27 - 2.34
Large	1.80	1.50 - 2.06
HONDURAS		
Small	1.25	0.68 - 1.94
Medium	1.23	0.84 - 1.94
Large	1.28	0.84 - 1.65
THAILAND		
Small	0.45	0.22 - 0.99
Medium	0.42	0.12 - 0.60
Large	0.51	0.32 - 0.68

Consumers in the Philippines paid prices ranging from $0.97 to $2.34 per kilogram for tilapia; one kilogram of fish is equivalent to 5-6 smaller fish. Often this meant one fish for each family member. In comparison, the price for fish in Honduras ranged from $0.68 to $1.65 per kilogram of fish; one kilogram of fish equivalent to three bigger fish. Honduran and Thai consumers preferred a larger fish than purchasers in the Philippines.

In Thailand, tilapia prices were much lower than in the Philippines or Honduras. Tilapia prices ranged from $0.12 to $0.99 per kilogram of fish; one kilogram of tilapia is two or three fish. Tilapia in Thailand are ubiquitous and supply is abundant. This may account for the low price range. Additionally, the sale of tilapia to middlemen who harvest the fish results in a lower price to the farmer. The cost of labor to harvest is reflected in a reduced tilapia purchase price.

Prices received by Honduran tilapia farmers had the most variation. Some low-intensity, rural farmers had little opportunity for marketing their fish, and the prices they obtained were low. The predominant tilapia size harvested in Honduras was in the 200 to 300 gram range for producers with small and medium-area ponds and greater than 500 grams for larger farms. The largest Honduran farms grew larger tilapia primarily for export of frozen and fresh fillets.

Market Constraints

Identifying the market in which the cultured tilapia are to be sold is an essential element in determining production-marketing viability (Table 3). An understanding of the product characteristics and consumer preferences associated with the selected market is fundamental in developing the appropriate production technology.

Where aquaculture is a new enterprise, there may be little or no organized fish marketing. Development of marketing infrastructure for aquacultural inputs and outputs will often be as important as soil, water, climate, and nutrients to the economic viability of aquaculture.

Small-scale farmers who consume most of their fish harvest or sell it locally have a restricted need for marketing information. The farmer may be personally acquainted with most of the final consumers of his product. As the percent of home consumption decreases and distance to final consumer increases, however, marketing channels become more important. Specific information on

Table 3. Composition of tilapia according to pond area in Honduras, the Philippines, and Thailand, 1994.[1]

Item	All	Honduras			Philippines			Thailand		
	(%)	Small (%)	Medium (%)	Large (%)	Small (%)	Medium (%)	Large (%)	Small (%)	Medium (%)	Large (%)
Sold Tilapia Last Harvest	87	80	88	100	94	100	100	100	100	100
Sold to:										
Middlemen	69	19	50	80	55	84	100	93	93	93
Restaurants	13	13	31	47	--	5	19	7	--	--
Marketplace	14	13	--	13	39	32	19	7	--	--
Other buyers	70	88	75	87	89	63	69	79	50	50
(Number)	(11)	(15)	(16)	(15)	(18)	(19)	(16)	(14)	(14)	(15)

[1] Column percentages will be greater than 100 because of multiple responses given by each respondent.

consumer and product characteristics is crucial to expanding markets and maintaining a favorable price.

Sixty percent of the Rwandan farmers did not sell any fish from their last harvest. In the small and medium categories, Honduran respondents kept higher percentages of their harvested fish for home consumption, 20 and 12%, respectively, than respondents in the Philippines or Thailand. The percentage of farmers keeping some tilapia for home consumption decreased as pond area increased, suggesting that increased pond area was associated with increased entry into the cash market economy.

In the Philippines, small pond operators did not sell all their fish and kept some for home consumption. Medium and large pond owners sold 100% of their harvests. No Thai respondents, at any pond area, kept fish for home consumption; all were sold.

Rwandan farmers sold fish to other buyers—teachers, civil servants, and others making direct purchases; family members also sold fish in the marketplace. Thai, Philippine, and Honduran fish were sold mainly to intermediaries, other buyers, and restaurants or by family members in the marketplace. Between 5 and 19% of the Philippine farmers were able to sell their fish to restaurants. About 13 to 47% of the Honduran farmers sold fish to restaurants, but only a few Thai farmers reported sales to restaurants. Honduran restaurant sales were much higher than in any other country. Few Thai and Honduran farmers personally sold any fish in the marketplace.

Problems in Marketing Tilapia

More than two-thirds of the people surveyed said they had no problem marketing tilapia (Table 4). There was concern in Thailand by the farmers that they were not getting the price they wanted. Many also responded that they could not sell their fish even when they lowered their prices. Similar comments were also made by Philippine and Honduran tilapia farmers.

Approximately one-third of the farmers in Rwanda did not eat fish. In a study of people practicing aquaculture in Rwanda, Molnar et al. (1991) found that fish were considered a recent entry into traditional diets, except in some lake areas. No cultural taboos toward eating fish were discovered although knowledge of fish preparation methods was limited. Consumers exhibited a clear size preference for marketed tilapia. In Rwanda, fish greater than 120 grams sold quickly at $2.00/kg, but fish weighing less than 100 grams would not be purchased, even at reduced prices. However, this size bias changed by region, with consumers in some lake regions accepting smaller fish. A 120-gram fish was attainable in 7 to 9 months by farmers that followed recommended management practices.

Three-quarters of the Rwandan farmers felt a larger fish would be easier to sell. In Thailand and

Table 4. Marketing problems of tilapia farmers in Rwanda, the Philippines, Honduras, and Thailand, 1994.

	Rwanda	Honduras	Philippines	Thailand
	Pct.	*Pct.*	*Pct.*	*Pct.*
Did you have trouble selling your tilapia?				
No	79	82	100	69
Yes	21	18	0	31
Had problems selling at price you want?				
No	77	90	100	44
Yes	23	10	0	56
Even if you cannot get the price wanted, can you usually sell at a lower price?				
No	27	36	76	50
Yes	13	64	24	50
Some people in area do not like to eat tilapia?				
No	66	84	100	85
Yes	34	16	0	15
Larger tilapia would be easier to sell?				
No	28	58	15	4
Yes	72	42	85	96
Sold fingerlings to other farmers?				
No	49	84	74	94
Yes	51	16	26	6
Did you have trouble selling fingerlings?				
No, did not sell	42	84	70	94
Had no problems	31	16	30	4
Yes, problems	27	0	0	2
(Number)	(136)	(51)	(50)	(56)

the Philippines, almost all of the respondents felt larger fish would sell more easily. In Honduras, approximately half the operators felt a larger fish would sell more easily.

Conclusion

Marketing strategies for tilapia varied from primarily home consumption to widely distributed markets. Marketing channels for these farmers were not investigated fully. Much more can be done to improve these channels not only for fish distribution but also for production inputs to the farmers.

The many institutional actors working in aquaculture perhaps should be considered the primary audience for a global research project such as the PD/A CRSP. Some level of direct farmer contact and training is necessary for keeping PD/A CRSP scientists in touch with the direct experiences and problems of fish farmers. Nonetheless, the impacts and influence of the PD/A CRSP may be greater if institutions and industry are understood to be the primary consumers of PD/A CRSP outcomes.

Thus, seminars for nongovernmental organizations (NGOs) that maintain extensive and long-term relationships with villages and small-scale farmers may be the most important mechanism for reaching this constituency rather than direct intervention by the PD/A CRSP. As long as small- and medium-scale farmers remain a central target segment for PD/A CRSP research, the development of a continuing network of contacts with representatives of these groups will be a significant objective for the research network. The NGOs may be more effective at stimulating interest and reaching small-scale farmers than governmental organizations or the limited and sporadic activities of PD/A CRSP personnel (Kaimowitz, 1993).

To gain greater leverage for PD/A CRSP activities, a number of strategies might be consciously highlighted for PD/A CRSP scientists. These include instructing NGO trainers, encouraging NGOs to adopt aquaculture as part of their repertoire of assistance activities, and helping national institutions organize seminars and training programs for NGOs. These and other means may be used for wholesaling PD/A CRSP technology to actors closer to village life who will be there when PD/A CRSP is not.

Literature Cited

Bailey C., S. Jentoff, and P. Sinclair (Editors), 1996. Social and Environmental Aspects of Aquacultural Development. Westview Press, Boulder, Colorado, 289 pp.

Ben-Yami, M., 1986. Aquaculture: the importance of knowing its limitations. Ceres, 112:15-19.

Casley, D.J. and K. Kumar, 1988. The Collection, Analysis, and Use of Monitoring and Evaluation Data. Johns Hopkins University Press, Baltimore, 346 pp.

Castillo, S., T.J. Popma, R.P. Phelps, L.U. Hatch, and T.R. Hanson, 1992. Family-Scale Fish Farming in Guatemala, Research and Development Series No. 37. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama, 52 pp.

Cernea, M., 1991a. Putting People First: Sociological Variables in Rural Development. The World Bank, Washington, DC, 328 pp.

Cernea, M., 1991b. Using Knowledge from Social Science in Development Projects. Discussion Paper Number 114: The World Bank, Washington, DC, 28 pp.

Coughenour, C.M., 1992. A new agenda for CRSP social science research. In: C.M. Coughenour (Editor), Proceedings of the Workshop on Social Science Research and the CRSPs. Department of Rural Sociology, University of Kentucky, Lexington, pp. 67-82.

Engle, C.R., 1987. Women in training and extension services in aquaculture. In: E.E. Nash, C.R. Engle, and D. Crosetti (Editors), Women in Aquaculture. ADCP/REP/87/28. Food and Agricultural Organization of the United Nations, Rome, pp. 57-72.

Hatch, U., T. Hanson, T. Popma, and R. Phelps, 1995. Family-scale fish farming in Guatemala (part ii): Economic viability. Journal of Aquaculture in the Tropics, 10:57-72.

Hatch, U. and T. Hanson, 1991. The Economics of Aquaculture: A Review. Mimeo. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama, 345 pp.

Harrison, E., 1991. Aquaculture in Africa: Socioeconomic Dimensions, A Review of the Literature. Mimeo. School of African and Asian Studies, University of Sussex, Brighton, England, 45 pp.

Harrison, E., 1995. My pond has no fish: Aquaculture Development in Luapula Province, Zambia. School of African and Asian Studies, University of Sussex, Brighton, England, 245 pp.

Kaimowitz. D., 1993. The role of nongovernmental organizations in agricultural research and technology transfer in Latin America. World Development, 21:1139-1150.

Lightfoot, C., S. Feldman, and M. Zainul Abedin, 1991. Household, Agroecosystems, and Rural Resources Management. Educational Series No. 12. International Center for Living Aquatic Resource Management, Manila, The Philippines, 45 pp.

McCorkle, C. M. (Editor), 1989. The Social Sciences in International Research: Lessons from the CRSP. Lynn Riener, Boulder, Colorado, 256 pp.

Moehl, J. and J. Molnar, 1995. Dilemmas of Aquacultural Development in Rwanda. In: C. Bailey, S. Jentoff, and P. Sinclair (Editors), Social and Environmental Aspects of Aquacultural Development. Westview Press, Boulder, Colorado, pp. 260-89.

Molnar, J.J. and B.L. Duncan, 1989. Monitoring and evaluating aquaculture projects. In: R.B. Pollnac (Editor), Monitoring and Evaluating the Impacts of Small-Scale Fishery Projects. International Center for Marine Resource Development, University of Rhode Island, Kingston, pp. 28-40.

Molnar, J.J., N.B. Schwartz, and L.L. Lovshin, 1985. Integrated aquacultural development: sociological issues in the cooperative management of community fishponds. Sociologica Ruralis, XXV:61-80.

Molnar, J.J., V. Adjavon, and A. Rubagumya, 1991. The sustainability of aquaculture as a farm enterprise in Rwanda. Journal of Applied Aquaculture, 12:37-62.

Molnar, J., C. Cox, A. Rubagumya, and P. Nyirahabimana, 1993. Socioeconomic Factors Affecting the Transfer and Sustainability of Aquaculture Technology in Rwanda. Research and Development Series 35. International Center for Aquaculture and Aquatic Environments, Auburn University, AL, USA.

Molnar, J., C. Cox, A. Rubagumya, and P. Nyirahabimana, 1994. Socioeconomic Factors Affecting the Transfer and Sustainability of Aquaculture Technology in Rwanda, Research and Development Series 35. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama, 289 pp.

Molnar, J.J., T.R. Hanson, and L.L. Lovshin, 1996. Social, Institutional, and Economic Impacts of Aquacultural Research: The Pond Dynamics/Aquaculture CRSP in Rwanda, Honduras, the Philippines, and Thailand. Research and Development Series No. 40. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama, 289 pp.

Pollnac, R., 1992. Coastal Aquaculture in Developing Countries: Problems and Perspectives, International Center for Marine Resource Development, University of Rhode Island. Kingston, 224 pp.

Rothe, M.K. Wiebe, and S. Lawry, 1992. Land tenure and agrarian structure: implications for technology adoption. In: C.M. Coughenour (Editor), Proceedings of the Workshop on Social Science Research and the CRSPs. Department of Rural Sociology, University of Kentucky, Lexington, pp. 157-177.

Smith, L.J. and S. Peterson (Editors), 1982. Aquaculture Development in Less Developed Countries: Social, Economic, and Political Problems. Westview Press., Boulder, Colorado, 289 pp.

Central America

PD/A CRSP researchers from Auburn University, and the Laboratorio de Calidad de Agua in Choluteca, as well as farm operators from the Grupos Granjas Marinas, Honduras, tested the effects of dietary protein (20 and 40%) and feeding rate on food conversion (FCR) and nitrogen discharge in the semi-intensive production of shrimp (*Penaeus vannamei*). Researchers found that neither a high feeding rate nor a high protein level in the diet of *Penaeus vannamei* affected production. Shrimp yields were not significantly higher at high feeding rates, and FCRs were very high. This indicated that the shrimp were overfed. Because shrimp were overfed the design of the low feeding rate treatment was undermined, and conclusions cannot be drawn regarding the effects of a high protein diet at very low feeding rate. Ponds from this study had a net discharge of organic material measured as total nitrogen, total phosphorus, chlorophyll-*a*, and BOD_2, and a net consumption of inorganic nitrogen. There was also a net discharge of filterable phosphate from the high feeding rate treatments and a net accumulation of filterable phosphate in the low feeding rate treatment. Research results corroborated previous studies conducted in Choluteca—as feeding becomes more efficient, the impacts of shrimp farming on estuarine environment should decrease.

In a companion study conducted during the dry season, researchers tested the effects of dietary protein and feeding rate on feed conversion and nitrogen discharge in the semi-intensive production of *Penaeus vannamei*.. Dietary protein level did not affect shrimp yields, which confirms results from previous studies. Increased feeding rate with the 20% protein feed did result in significantly greater shrimp yield; however, neither final individual shrimp weight nor survival differed significantly. Researchers suspected that shrimp survival was partially responsible for differences in shrimp yields rather than the two feeding rates, 50 and 75% of the feeding curve, for the 20% protein feed. Survival of shimp given the 20% protein feed at 50% of the feed curve was 5.2% lower than of the shrimp offered 20% feed at 75% of the feed curve. Further, research results concurred with prior studies indicating that minimal shrimp growth occurs after 11 to 12 weeks of culture during the dry season in Honduras. Profits may be reduced if shrimp culture is continued beyond 12 weeks. Low FCRs indicated that efficient feed management strategies were employed. With lower FCR values, the potential pollution impacts of pond effluents are reduced, because less nitrogen and phosphorus are added to ponds.

In an ongoing effort, the Honduras team continued to monitor estuarine water quality. The data collected supplemented a baseline of information established on selected chemical, biological, and physical characteristics of water at points along major shrimp producing estuaries in southern Honduras. The objective of this study was to detect trends over time regarding the impacts of shrimp farming on water quality. Preliminary results of monitoring since the inception of the project in 1993 indicate that total nitrogen concentrations have not increased with time; however, farm management to minimize effluents during the dry season is critical for preventing eutrophication of estuaries and conditions not able to sustain shrimp culture.

Fish reproduction is another focal point of CRSP research. In general, the oral administration of 17α-methyltestosterone (MT) is used for the sex reversal of newly hatched tilapia. Research to determine the optimal dose of MT to date has yielded inconsistent results. This may be due to environmental influences during the treatment. Therefore, PD/A CRSP researchers at Auburn University conducted studies to determine the efficacy of different dosages of MT for sex reversal when tilapia were held either indoors or outdoors. In addition the scientists evaluated the potential of freeze-dried bull testes as a dietary source of testosterone for tilapia sex reversal. Naturally occurring sources of testosterone may be a potential alternative to synthetic androgens for tilapia sex reversal.

Freeze dried bull testes were not effective in producing male tilapia populations of 95% or greater. The percentage of males obtained when bull testes composed half of the ration was significantly greater than non-treated populations; however, the percentage was too low to be practical. The effectiveness of 17α-methyltestosterone (MT) was not affected by either indoor or outdoor treatments. Differences were not found in the efficacy of treatment dosages. Populations composed of greater than 97% males resulted from treatment rates of 15, 30, 45, and 60 mg MT/kg of diet. Survival rates were low after a 28-d MT treatment period, with survival in aquaria ranging from 16.7-27.7% and 25.7-43.6%, and survival in hapas ranging from 25.7 -43.6%. In addition feed ratios appeared to influence survival rates. Fry given feed containing bull testes on a 1:1 ratio was 28.3%, and 69.2% for fry given 1:3 feed ratio.

Effect of Diet Protein on Food Conversion and Nitrogen Discharge during Semi-Intensive Production of *Penaeus vannamei* during the Wet Season

Interim Work Plan, Honduras Study 1 (Part I)

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Introduction

Prior reasearch demonstrated that shrimp production was similar at protein levels ranging from 20 to 40%, when shrimp were stocked at densities ranging from 5 to 11/m² (Teichert-Coddington and Rodriguez, 1995). Many producers feed diets containing protein levels of 27% and higher during at least a part of the growing season. It appears that economic efficiency of production could be improved by reducing protein levels in the diet.

The reduction of feeding rates, particularly during the dry season may also improve production efficiency. Dry season production of shrimp juveniles stocked at 7.5/m² was not significantly affected by a 50% reduction in the conventional feeding rate (Teichert-Coddington and Rodriguez, 1994). Wet season production was not significantly impacted by reducing the feeding rate by 50%, but feeding efficiency was improved.

These data indicate that both protein content of feed and rates of feeding could be reduced during at least part of the year without reducing shrimp yields. However, it is possible that a comparatively high protein diet fed at a comparatively low rate might result in higher feed conversion than a low protein diet fed at a higher rate.

Phytoplankton blooms in riverine estuaries of southern Honduras appear to be limited by nitrogen. Blooms can result in anoxic conditions at night when respiration by a large plankton biomass consumes oxygen. Highly fertile estuarine water is, therefore, inadequate for replacing water in production ponds.

Nutrient discharge from farms contributes to estuarine fertility. Chemical budget studies of large commercial ponds indicated that nitrogen discharge increased with both feeding rate and diet protein level (Teichert-Coddington et al., 1996). Better feed conversion should result in less nitrogen discharge as well as decreased operating costs. The objective of this experiment was to evaluate the effect of diet protein level and feeding rate on yield, food conversion, and nitrogen effluent during the production of *Penaeus vannamei* at semi-intensive stocking levels.

Materials and Methods

A completely randomized design with a 2 X 2 factorial arrangement was used to test two feeding rates at two levels of protein. Feeding rates were 50 or 75% of the standard feeding curve, and crude protein content was 30 or 20% of the feed (Table 1). Each treatment was replicated. The feeding curve was described by the following equation:

$$Y = 10^{-0.899 - 0.561 \mathrm{Log}_{10}(X)}$$

where,

Y = % of biomass; and

X = mean weight of shrimp (g).

Equal quantities of feed were added to replicate ponds within a treatment based on the average weight of shrimp from the three replicates.

Post larval *Penaeus vannamei*, spawned in a hatchery, were stocked at 24/m^2 (240,000/ha) in earthen ponds ranging in area from 0.7 to 2.0 ha. It was assumed that the survival rate was 30% due to Taura Syndrome, and that most of the mortality (75%) would occur during the first five weeks.

Water samples for chemical analyses were taken from supply canals and from water discharged during weekly water exchanges. Salinity, Secchi disk, total nitrogen, nitrate nitrogen, total ammonia, BOD_2, and pH were determined weekly. Total phosphorus and filterable phosphate were determined every two weeks, and total alkalinity and primary productivity (free-water method) were determined three times during the experiment. Temperature and dissolved oxygen were determined daily with a YSI meter. Total settleable solids were measured at harvest. Nutrients discharged during harvest were determined from a weighted mean of concentrations determined from water sampled at 100%, 10%, and 0% of pond volume.

Water was exchanged once a week at a nominal rate of 10% of pond volume assuming a depth of 0.9 m. Later measurements demonstrated that mean pond depth actually varied from 0.9 m, hence the percentage of water exchange also varied. Water exchange was accomplished by first draining and then refilling the pond. If morning dissolved oxygen concentration was lower than 2.5 mg/l, then 5% of pond volume was exchanged. Records were kept of exchange events. Total material exchange in the pond during weekly water exchange was calculated by subtracting the mass discharge from the mass intake.

A chemical budget excluding the soils component was made for nitrogen. The general balance equation was:

$$S_{in} + F_{in} + PWV_{in} + WE_{in} = S_{out} + PWV_{out} + WE_{out} \pm Ø≠$$

where,

S = shrimp;

F = feed;

PWV = pond water volume; and

WE = water exchange.

Feed was analyzed for nitrogen content; nitrogen composition of shrimp was 25.5% of dry matter (Boyd and Teichert-Coddington, 1995).

Shrimp were harvested by completely draining ponds on 6 December 1995, 118 days after stocking. Total weight of shrimp was measured for each pond. Mean shrimp weight for each pond was determined by counting and weighing 400 shrimp each at the beginning, middle, and end of harvest. Shrimp were weighed in groups of 100.

Data were analyzed by 2-factor ANOVA where protein content of feed and feeding rate were factors. Survival and water exchange data were arcsine transformed before statistical analysis. Material exchange by water was calculated by subtracting the mass of nutrient discharged from the mass of nutrient input. Treatment differences were declared significant at alpha = 0.05.

Results

Mean treatment pond area was 1.6 ha. Mean treatment pond volumes and weekly water exchange rates were not significantly different. Pond volumes ranged from 0.9 to 1.1 ha-m and weekly water exchange was 59 to 74% of pond volume (Table 2).

Protein level in the diet had no significant effect on gross shrimp yield, mean shrimp size, or feed conversion (Table 2). Survival was significantly

Table 1. Shrimp diet containing 20% or 30% crude protein.

Ingredient	20% Protein	30% Protein
White Corn	42.5	14.0
Wheat Midds	23.9	33.5
Soy 48.5%	10.8	26.1
Fish Meal 67%	9.0	15.0
Calcium Carbonate	3.9	2.9
Meat & Bone Meal	2.0	2.0
Rice Bran	5.9	4.5
Maxi-Bond	2.0	2.0
Total	100.0	100.0

higher in low protein treatments than in high protein treatments although mean differences were low. Mean survival was 22.2 and 19.3% for low and high protein treatments, respectively.

Feeding rate had no significant effect on gross yield, mean size, or survival; however, the mean feed conversion ratio (FCR) was significantly higher for the high feeding rate than for the low feeding rate treatment. No interaction was detected between protein level and feeding rate for yield, mean shrimp size, or FCR.

Nutrient concentrations of intake and discharge water are summarized in Table 3. Differences among treatments were not detected among mean discharge concentrations.

Mean material exchange via water in the pond was negative (greater mass discharge than mass intake) in all treatments for total nitrogen, total phosphorus, chlorophyll-*a*, and BOD_2 (Table 4). Greater masses of total ammonia nitrogen and nitrates were taken into the pond than were discharged, and mean weekly filterable phosphate exchange ranged from -9 to + 73 g/ha. Mean differences among treatments were not significant with one exception—significantly greater quantities of filterable phosphate were discharged by the high feeding rate than by the low feeding rate treatments. Mean discharge of total nitrogen for the high protein treatment was more than twice that for the low protein treatments; however, the differences were not significant because of high within-treatment variation.

Table 2. Mean production (± SD) of *P. vannamei* stocked 24 post larvae/m^2 and fed high or low rates of feed containing 20% or 30% crude protein.

Variable	20%; Low	20%; High	30%; Low	30%; High	Effects		
					Protein	*Rate*	*Interaction*
Gross Yield (kg/ha)	597 ± 148.5	687 ± 52.5	560 ± 119.3	668 ± 74.0	ns	ns	ns
Mean Size (g)	12.6 ± 0.96	12.0 ± 1.48	12.6 ± 0.12	13.9 ± 0.90	ns	ns	ns
Survival	20 ± 2.6	24 ± 2.3	20 ± 2.0	19 ± 0.6	*	ns	*
FCR	2.50 ± 0.47	3.04 ± 0.29	2.58 ± 0.30	3.66 ± 0.23	ns	**	ns
Water Exchange (%/wk)	59 ± 51	71 ± 65	62 ± 51	74 ± 50	ns	ns	ns

** Differences were highly significant (P < 0.01).
* Differences were significant (P < 0.05).
ns: Differences were not significant (P > 0.05).

Table 3. Mean nutrient concentrations of intake and discharge water from ponds stocked with *P. vannamei* fed high or low rates of feed containing 20% or 30% crude protein.

Variable	Intake	Discharge				Effects		
		20%; Low	*20%; High*	*30%; Low*	*30%; High*	*Protein*	*Rate*	*Interaction*
Total Nitrogen (mg/l)	0.82 ± 0.04	0.92 ± 0.37	0.93 ± 0.18	1.32 ± 0.58	1.13 ± 0.26	ns	ns	ns
Total Ammonia-N (mg/l)	0.14 ± 0.022	0.07 ± 0.013	0.07 ± 0.020	0.07 ± 0.013	0.07 ± 0.002	ns	ns	ns
Nitrate+Nitrite-N (mg/l)	0.040 ± 0.018	0.004 ± 0.004	0.004 ± 0.002	0.003 ± 0.002	0.004 ± 0.001	ns	ns	ns
Total Phosphorus (mg/l)	0.21 ± 0.007	0.22 ± 0.013	0.23 ± 0.025	0.24 ± 0.056	0.26 ± 0.007	ns	ns	ns
Filterable Phosphate (mg/l)	0.105 ± 0.016	0.09 ± .026	0.09 ± 0.018	0.08 ± 0.004	0.10 ± 0.020	ns	ns	ns
Chlorophyll-*a* (μg/l)	39.2 ± 5.0	57.7 ± 25.9	51.0 ± 16.4	92.1 ± 60.6	65.6 ± 12.3	ns	ns	ns
BOD_2 (mg/l)	2.8 ± 0.5	4.8 ± 1.9	3.9 ± 0.6	5.1 ± 2.0	4.8 ± 0.4	ns	ns	ns

ns: Differences were not significant (P > 0.05).

More total nitrogen was introduced into ponds by shrimp, water, and feed than was removed from ponds as harvested shrimp and discharge water (Table 5). The mean treatment difference between input and output nitrogen for the high feeding rate was significantly higher than for the low feeding rate.

Discussion

This experiment was designed to evaluate effects on shrimp yield, FCR, and nitrogen effluents of feeding a low-protein diet at a relatively high rate and feeding a high-protein diet at a relatively low rate. The feeding curve, used as a reference in this study, ranged from 10.8 to 2.5% of biomass per day for shrimp weighing from 1 to 18 g. Previous reasearch had demonstrated that this rate of feeding was too high for semi-intensive shrimp culture, and resulted in high FCRs, particularly during the dry, cool season (Teichert-Coddington and Rodriguez, 1994). The standard feeding rate was consequently reduced to 75% of the curve. This reduced rate constituted the high feeding rate treatment used in this experiment.

Some producers claimed that FCRs could be improved by feeding at very low rates if the feed contained a relatively high level of protein. This theory implies that protein quality may impact production if protein quantity applied as feed is low. Prior research had demonstrated no significant effect on shrimp production or FCRs if the protein level was increased from 20 to 40% at stocking rates ranging from 5 to 11/m^2 (Teichert-Coddington and Rodriguez, 1995). FCRs were as high as 2.56 in the experiment and were considered by some producers too high for the high-protein diet to be effective. The current experiment was designed to evaluate this assumption by testing for interaction between feeding rate and protein level. The low feeding rate used in the current experiment had been tested in a prior study and appeared to be insufficient for optimum yield (Teichert-Coddington and Rodriguez, 1994).

There were no significant treatment differences for production variables, indicating that neither a high feeding rate nor a high protein level in the diet affected production. There was no interaction between feeding rate and protein level, indicating that a high protein diet fed at a low rate did not influence production any more than a low protein diet at a low rate.

Shrimp yields were not significantly higher at the high feeding rate; and FCRs were high, especially with the high feeding rate. These results indicated that shrimp were overfed. Indeed, overfeeding resulted for three reasons. First, with reference to the feeding curve, shrimp were overfed during weeks two through six, because the computer-generated feeding schedule did not take into account mortality which should have been 53% by week five. The schedule was corrected by week seven. Second, stocking of the ponds was delayed by six weeks, so almost half the study took place during the cool season of the year, when growth is historically one half or less of warm season growth (Teichert-Coddington et al., 1994). Dry,

Table 4. Mean treatment nutrient exchange (± SD) per weekly water exchange event with respect to pond area or pond volume. Nutrient exchange was calculated by subtracting nutrient discharge from nutrient intake. Values in parentheses are negative (greater nutrient discharge than nutrient intake).

Variable	% Protein; Feeding Rate				Effects		
	20%; Low	*20%; High*	*30%; Low*	*30%; High*	*Protein*	*Rate*	*Interaction*
Total N (g/ha)	(1100) ± 1613	(887) ± 1014	(2611) ± 1771	(2527) ± 1252	ns	ns	ns
Total Ammonia - N (g/ha)	245 ± 123	130 ± 133	274 ± 159	243 ± 358	ns	ns	ns
Nitrate + Nitrite - N (g/ha)	73 ± 36	105 ± 33	85 ± 56	117 ± 47	ns	ns	ns
Total Phosphorus (g/ha)	(12) ± 156	(25) ± 117	(25) ± 206	(132) ± 18	ns	ns	ns
Filterable Phosphate-P (g/ha)	23 ± 60	(9) ± 27	73 ± 27	(13) ± 30	ns	*	ns
Chlorophyll-*a* (g/ha)	(91) ± 105	(23) ± 76	(239) ± 203	(99) ± 9	ns	ns	ns
BOD_2 (kg/ha)	(9.2) ± 6.1	(5.9) ± 2.4	(10.8) ± 4.2	(10.7) ± 2.8	ns	ns	ns

* Differences were significant ($P < 0.05$).
ns Differences were not significant ($P > 0.05$).

Table 5. Mean difference (± SD) between nitrogen input and measurable nitrogen output during 118 d of shrimp culture in earthen ponds. Values in parentheses are negative.

Variable	% Protein; Feeding Rate				Effects		
	20%; Low	20%; High	30%; Low	30%; High	*Protein*	*Rate*	*Interaction*
Input Shrimp (kg/ha)	0.53 ± 0.29	0.53 ± 0.21	0.47 ± 0.15	0.60 ± 0.26	ns	ns	ns
Input Water (kg/ha)	43.1 ± 29.2	42.6 ± 29.6	43.2 ± 30.0	42.7 ± 30.0	ns	ns	ns
Input Feed (kg/ha)	44.2 ± 1.6	63.9 ± 8.4	66.7 ± 13.6	113.5 ± 7.0	**	**	*
Total Input (kg/ha)	87.9 ± 28.8	107.1 ± 21.8	110.3 ± 30.3	156.8 ± 35.1	ns	ns	ns
Output Shrimp (kg/ha)	17.0 ± 4.3	19.6 ± 1.5	16.0 ± 3.4	19.1 ± 2.1	ns	ns	ns
Output Water (kg/ha)	55.8 ± 25.5	53.2 ± 20.4	73.6 ± 30.0	71.4 ± 40.6	ns	ns	ns
Total Output (kg/ha)	72.9 ± 27.3	72.8 ± 19.4	89.6 ± 28.8	90.5 ± 42.4	ns	ns	ns
Input - Output (kg/ha)	15.0 ± 22.1	34.3 ± 9.2	20.7 ± 31.1	66.3 ± 14.8	ns	*	ns

* Differences were significant ($P < 0.05$).
** Differences were highly significant ($P < 0.01$).
ns Differences were not significant ($P > 0.05$).

cool season feeding rates should be further reduced (Teichert-Coddington and Rodriguez, 1994) because shrimp consume less feed. Production during this study was about half of expected yields, partly because of the cool season effects. Third, mortality from Taura Syndrome was projected to be 70%, but actual mortality averaged 79%, so shrimp biomass was overestimated when calculating feed inputs.

Overfeeding of shrimp violated the low feeding rate treatment designed to underfeed shrimp. Conclusions, therefore, cannot be drawn about the effects of a high-protein diet at a very low feeding rate. Otherwise, these results supported earlier conclusions that a higher protein level in the diet did not result in higher yields or better FCR (Teichert-Coddington and Rodriguez, 1995). Hopkins et al. (1994) arrived at similar conclusions when cultivating shrimp at high densities with a 20 or 40% protein diet in ponds without water exchange.

Ponds had a net discharge of organic material, measured as total nitrogen, total phosphorus, chlorophyll-*a*, and BOD_2, and a net consumption of inorganic nitrogen. There was a net discharge of filterable phosphate from the high feeding rate treatments and a net accumulation of filterable phosphate in the low feeding rate treatment. These results are very similar to those reported by Teichert-Coddington et al. (1996), where inorganic nitrogen and phosphorus from estuarine intake water were converted to organic matter within the pond. Inorganic nitrogen and phosphorus tend to accumulate in the estuaries probably because sediments, suspended due to high tidal action, limit primary productivity by blocking sunlight. Sediment precipitation in water supply canals and ponds thereby allowed phytoplankton to bloom.

Teichert-Coddington et al. (1996) reported that nitrogen discharge from commercial shrimp ponds increased with higher FCRs. In this study, significant treatment differences were not detected for net discharge of nitrogen (Table 4) although there were higher inputs of nitrogen with the high protein diet supplied at the high feeding rate. Nitrogen that was not detected in water discharge or shrimp harvest was significantly greater at the high feeding rate (Table 5). Unobserved nitrogen averaged 17 and 37% for low and high feeding rates, respectively. This is higher than the 1% value formerly reported for semi-intensive, commercial ponds in Honduras (Teichert-Coddington et al., 1996). Higher proportions of input nitrogen not detected in water discharge or shrimp harvest were reported for intensively managed shrimp ponds. Briggs and Funge-Smith (1994) determined that 44% of input nitrogen was undetected in discharge water or shrimp flesh from ponds in Thailand, and Hopkins et al. (1993) reported rates ranging from 9 to 67% for ponds in South Carolina. Both of the intensively managed pond studies demonstrated accumulation of nitrogen in soils and sludge, but could not otherwise account for 3 to 42% of total nitrogen input. Undetected nitrogen was assumed lost to denitrification. Research has not determined if significant amounts of nitrogen in shrimp ponds are fixed by algae, but nitrogen fixation may be important to the nitrogen budget of low-input shrimp ponds.

Anticipated Benefits

Results from this experiment have corroborated results from past studies in Choluteca. We can consequently make recommendations with more confidence with respect to reducing feeding rates and dietary protein levels. As feeding becomes more efficient, the impacts of shrimp farming on estuarine environment should become less.

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Literature Cited

Boyd, C.E. and D. Teichert-Coddington, 1995. Dry matter, ash, and elemental composition of pond-cultured *Penaeus vannamei* and *P. stylirostris*. Journal of the World Aquaculture Society, 26(1):88-92.

Briggs, M.R.P. and S.J. Funge-Smith, 1994. A nutrient budget of some intensive marine shrimp ponds in Thailand. Aquaculture and Fisheries Management, 25:789-811.

Hopkins, J.S., R.D.I. Hamilton, P.A. Sandifer, C.L. Browdy, and A.D. Stokes, 1993. Effect of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. Journal of the World Aquaculture Society, 24(3):304-320.

Hopkins, S.J., C.L. Browdy, P.A. Sandifer, and A.D. Stokes, 1994. Effect of two feed protein levels and two feed rates, stocking density combinations on water quality and production in intensive shrimp ponds which do not utilize water exchange. Abstract presented at Annual Meeting of the World Aquaculture Society in January 14-18, New Orleans, Louisiana, USA, p. 30.

Teichert-Coddington, D.R., D. Martinez, and E. Ramírez, 1996. Characterization of shrimp farm effluents in Honduras and chemical budgets of selected nutrients. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture Collaborative Research Program, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 70-84.

Teichert-Coddington, D.R. and R. Rodriguez, 1994. Inorganic fertilization and feed reduction in commercial production of *Penaeus vannamei* during wet and dry Seasons in Honduras. In: H.S. Egna, J. Bowman, B. Goetze, and

N. Weidner (Editors), Twelfth Annual Technical Report, Pond Dynamics/ Aquaculture Collaborative Research Program, International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 136-146.

Teichert-Coddington, D.R. and R. Rodriguez, 1995. Semi-intensive commercial grow-out of *Penaeus vannamei* fed diets containing differing levels of crude protein during wet and dry seasons in Honduras. Journal of the World Aquaculture Society, 26(1):72-79.

Teichert-Coddington, D.R., R. Rodriguez, and W. Toyofuku, 1994. Cause of cyclical variation in Honduran shrimp production. World Aquaculture, 25(1):57-61.

Effect of Diet Protein on Food Conversion and Nitrogen Discharge during Semi-Intensive Production of *Penaeus vannamei* during the Dry Season

Interim Work Plan, Honduras Study 1 (Part II)

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Introduction

Results of previous research have demonstrated that shrimp production is similar at protein levels ranging from 20 to 40%, when shrimp are stocked at densities ranging from 5 to 11/m^2 (Teichert-Coddington and Rodriguez, 1995a). These results indicated that shrimp stocked at semi-intensive levels did not require diets containing high levels of protein. However, some think that food conversion can be improved if a high-protein diet is employed. In order for food conversion to be improved, shrimp would either need to have better growth rates with the high-protein diet, or similar growth rates with less feed. A prior feed trial in Choluteca with shrimp stocked at 7.5/m^2 demonstrated that production during the dry season was not significantly affected by a 50% reduction in the feeding rate (Teichert-Coddington and Rodriguez, 1995b). Wet season production was significantly impacted by the 50% reduction in feeding although feeding efficiency was improved (Teichert-Coddington and Rodriguez, 1995b). These results indicated that shrimp were overfed normally during the dry season and that wet season rates could potentially be reduced although not cut in half. The objective of this experiment was to determine the effect of dietary protein and feeding rate on feed conversion and nitrogen discharge in the semi-intensive production of *Penaeus vannamei*.

Materials and Methods

Twelve ponds located at a commercial shrimp farm on a riverine estuary on the Gulf of Fonseca, Honduras, were used for this dry-season study. Ponds averaged 1.67 ± 0.07 ha, 0.57 ± 0.06 m, and 9431 ± 993 m^3, in area, depth, and volume, respectively. This study was originally designed to test four treatments (two feed protein levels at two feeding rates) but was modified because results of previous studies had shown little effect of feed rate during the dry season. We also felt that increasing the number of replicates per treatment from three to four would improve our ability to detect treatment differences. As only 12 ponds were available for the study, one of the initially proposed treatments was dropped. Thus, three treatments were tested: a 20% and a 30% protein feed applied at 50% of the feeding curve, and a 20% protein feed applied at 75% of the feeding curve. A completely randomized design with four replicates per treatment was used.

Ponds were stocked with hatchery-produced post-larval (PL) *Penaeus vannamei* at 325,000/ha on 19 January 1996. Stocking rate of PL shrimp was based on a historical survival rate due to Taura Syndrome of 25%, and was selected to achieve a final stocking rate of approximately 80,000 shrimp/ha. Most Taura Syndrome mortality occurs within the first month following stocking. Ponds were harvested 87 days after stocking.

Feed protein levels tested were 20% and 30% crude protein; a commercial ration manufactured locally by ALCON was used. Shrimp were offered feed six days per week beginning on 13 February 1996. Feed rate for each treatment was 50% or 75% of the theoretical feeding curve for *P. vannamei*:

$$\mathrm{Log}_{10}Y = -0.899 - 0.561\mathrm{Log}_{10}X$$

where,
Y = feed rate as a % of biomass; and
X = mean weight of shrimp in grams.

Daily feed rate was calculated for individual ponds and then averaged by treatment. All ponds within a treatment received the same quantity of feed on a daily basis. Feed was offered once each day. Cast net samples were taken weekly to monitor shrimp growth in each pond population. Feed rate was adjusted weekly based on shrimp samples. Feed conversion ratio was calculated as the weight of feed offered divided by gross whole shrimp yield.

Water was not exchanged during the first three weeks of culture; however, water was exchanged at 20% of the pond volume once per week beginning on week four. If early morning dissolved oxygen concentration was ≤ 2.5 mg/l, 5% of the pond volume was exchanged. In all water exchanges, pond level was lowered first and then refilled. Losses to seepage and evaporation were replaced weekly. Dates and quantities of all water additions and exchanges were recorded.

Pond water quality variables were measured upon initiation of the experiment, and beginning with initiation of scheduled water exchange on week four, discharge and replacement water quality was monitored weekly. Weekly discharge water samples were collected from each pond's outfall during water exchange. Because all ponds were supplied from a common water supply canal, water samples for replacement water analysis were collected at each extreme and the middle segment of the canal supplying the ponds. At harvest, water samples were collected at 0%, 10%, and 100% of pond volume for analysis. Initial pond water and replacement water samples were obtained with a column sampler. Water samples were analyzed for the following: 1) pH measured potentiometrically; 2) nitrate-nitrogen by cadmium reduction (Parsons et al., 1992), 3) total ammonia-nitrogen (Parsons et al., 1992); 4) filterable reactive phosphate (Grasshoff et al., 1983); 5) chlorophyll-*a* (Parsons et al., 1992); 6) total alkalinity by titration to pH 4.5 endpoint; 7) salinity; and 8) BOD_2 at ambient temperature. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation (Grasshoff et al., 1983).

Pond sediment samples were collected using a core sampler (4.2-cm ID) following pond inundation and prior to pond draining. Five to six core samples were collected along a transect across the width of the pond. Samples were collected along three transects per pond: near the inlet, the center, and the outlet. The methodology described by Munsiri et al. (1995) was followed to collect the top 2.5 cm of each soil core, prepare the sample for analysis, and analyze the sample. All core samples along a transect were pooled for analysis. Soils were analyzed for total phosphorus, total nitrogen, total carbon, sulfur, dilute acid-soluble phosphorus, metal ions, cation exchange capacity, and particle size.

The economic impact of substituting one feed management strategy for another was evaluated using a partial budget analysis (Kay, 1981). The 20% protein feed costs US $16.81/45.4 kg bag and the 30% protein feed costs $18.25/45.4 kg bag. Data were analyzed by ANOVA (Haycock et al., 1992). Percent data were arcsine transformed prior to analysis and differences were declared significant at alpha level 0.05.

Table 1. Production data (mean ± SD) from 1.67-ha semi-intensively managed earthen shrimp ponds where a 20% or 30% protein feed was tested. Feeding rate using the 20% protein feed was 50% or 75% of feeding curve and the feeding rate using the 30% protein feed was 50% of feeding curve. Post-larval shrimp were stocked to achieve a final stocking rate of approximately 80,000 shrimp/ha. Four replicate ponds were used per treatment.

Treatment	Gross Yield 1 (kg/ha/87d)	Mean Final Weight (g/shrimp)	Survival (%)	Feed Conversion Ratio
20% PROTEIN FEED				
50% of Feeding Curve	412 ± 50	6.1 ± 0.3	21.1 ± 0.0	1.0 ± 0.1
75% of Feeding Curve	534 ± 67	6.0 ± 0.5	26.3 ± 0.0	1.2 ± 0.1
30% PROTEIN FEED				
50% of Feeding Curve	490 ± 99	5.7 ± 0.4	31.0 ± 1.4	0.9 ± 0.1
Comparisons				
FEED PROTEIN LEVEL:				
20% Protein Feed v. 30% Protein Feed	NS	NS	NS	*
FEED RATE WITH 20% PROTEIN				
FEED:				
50% v. 75% of Feeding Curve	*	NS	NS	*

* Means differed significantly (P < 0.05).
NS: Means did not differ significantly (P > 0.05).
1 Gross yield of whole shrimp.

Results

Shrimp survival continued to decline as a result of Taura Syndrome, with mean survival ranging from 21 to 31%, and no significant differences noted among treatments (Table 1). Gross yields of head-on shrimp ranged from 412 to 534 kg/ha for the 87-day production period, and mean individual weights ranged from 5.7 to 6.1 g/shrimp (Table 1). Feed protein content did not affect gross shrimp yields significantly (Table 1). Gross yield of whole shrimp fed the 20% protein feed was significantly greater when the feed rate was 75% of the feeding curve compared with 50% of the feeding curve (Table 1). Neither mean final individual weight (Table 1) nor growth (Figure 1) of shrimp was affected significantly by feed protein content or feed rate. Feed conversion ratios (FCR) were close to one and were significantly lower with the 30% protein feed at the 50% feed rate (Table 1). Feed application was suspended during a 4 to 6-day episode of chronic low dissolved oxygen that occurred in ponds during week nine. Mean daily feed rate ranged from 8.1 to 13.1 kg/ha.

Feed additions to ponds totaled 398 kg/ha (20% protein feed-50% feed curve), 656 kg/ha (20% protein feed-75% feed curve), and 416 kg/ha (30% protein feed-50% feed curve). Quantities of 20% protein feed added to ponds were significantly greater than quantities of 30% protein feed added. Significantly more 20% protein feed was used at the 75% of feed curve rate than at the 50% of feed curve rate. Nitrogen and phosphorus additions to ponds as feed were significantly greater with the high-protein feed and the low-protein feed at the higher feed rate. However, feed nitrogen additions did not differ significantly between the 20% protein-75% feed curve treatment and the 30% protein-50% feed curve treatment, which were isonitrogenous. Nitrogen and phosphorus additions to ponds as feed were, respectively, 13.6 kg N/ha and 3.3 kg P/ha (20% protein feed-50% feed curve), 22.4 kg N/ha and 5.4 kg P/ha (20% protein feed, 75% feed curve), and 21.1 kg N/ha and 4.1 kg P/ha (30% protein feed-50% feed curve).

Shrimp tail-size distribution at harvest ranged from 51/60 count to 151/200 count, with 75% to 85% of the harvest being within the 91/110 to 131/150 range (Table 2). The value of the harvest ranged from US $1,308 to US $1,716 per hectare. Partial budget

Table 2. Mean distribution of tail sizes is expressed as a percentage of gross yield of shrimp tails and value of product by size classification.

Shrimp Tail Size Classification (count/lb)	Tail Price (US $/kg)	20% Protein Feed				30% Protein Feed	
		50% Feed Rate		*75% Feed Rate*		*50% Feed Rate*	
		Tail Size Distribution (%)	Value (US $/ha)	Tail Size Distribution (%)	Value (US $/ha)	Tail Size Distribution (%)	Value (US $/ha)
51/60	9.92	0.00	$0	0.25	$8	0.00	$0
61/70	8.82	1.00	$23	0.25	$8	0.00	$0
71/90	7.72	8.50	$174	14.00	$369	3.75	$87
91/110	6.61	30.75	$541	26.75	$605	21.50	$429
111/130	4.41	27.00	$317	26.25	$396	34.75	$463
131/150	3.31	20.75	$183	22.50	$254	29.25	$292
151/200	2.21	12.00	$70	10.00	$75	10.75	$72
Sum ($/ha):			$1,308		$1,716		$1,343

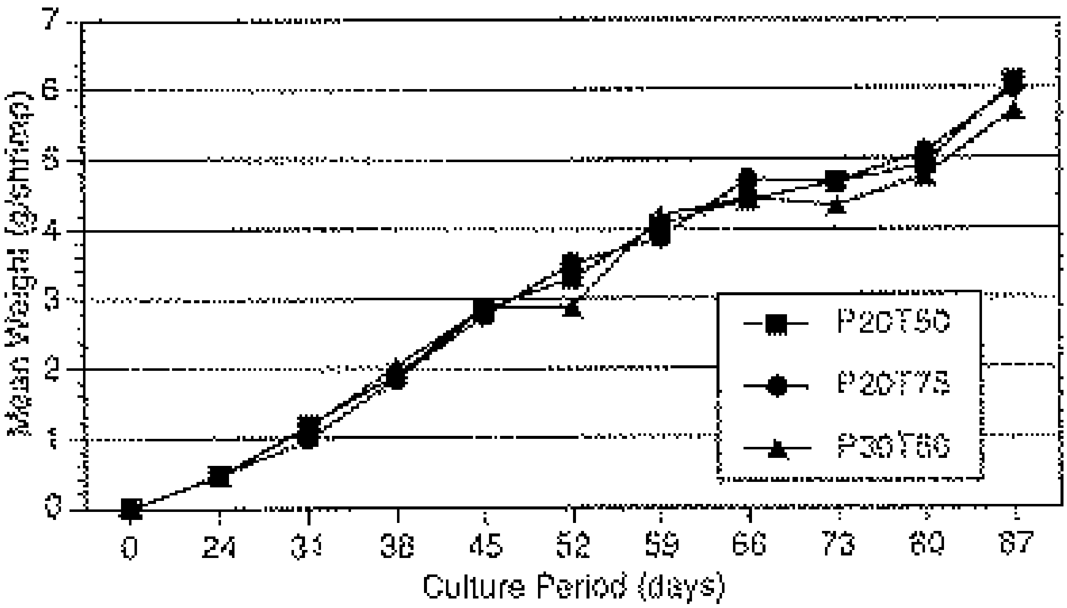

Figure 1. Growth of *P. vannamei* during an 87-day culture cycle in 1.67-ha earthen ponds receiving a 20% protein feed at 50% of feed curve (P20T50), a 20% protein feed at 75% of feed curve, or a 30% protein feed at 50% of feed curve (P30T50).

analysis of increasing feed rate from 50% to 75% of feed curve with the 20% protein feed showed a net change in profit of $313/ha. Change of feed management from a 20% protein feed-75% feed curve to a 30% protein-50% feed curve resulted in a net change in profit of $297/ha. Use of a 30% protein feed-50% feed curve in place of a 20% protein feed 50%-feed curve gave a net change in profit of $16/ha.

Salinity, total nitrogen and phosphorus, chlorophyll-*a*, and BOD_2 concentrations in inlet water were significantly lower than in pond water (Table 3). Nitrate was not detected in either inlet water or pond water. No significant differences were detected among treatment water quality means (Table 3); however, inorganic nitrogen and phosphorus introduced to ponds in inlet water were converted to organic forms. Although there

Table 3. Mean concentrations (± SD) of water quality variables from 1.67-ha shrimp ponds and water supply canal. Shrimp in four replicate ponds each were offered a 20% protein feed at 50% or 75% of feeding curve or 30% protein feed at 50% of feeding curve.

Variable	**Treatments**			**Water Supply Canal**
	20% Protein Feed		*30% Protein Feed*	
	50% Feed Rate	75% Feed Rate	50% Feed Rate	
Salinity (g/l)	28.6 ± 0.3 ab	29.0 ± 0.3 b	29.1 ± 0.5 b	28.2 ± 0.2 a
Total Ammonia Nitrogen (mg/l)	0.022 ± 0.005 a	0.025 ± 0.006 a	0.020 ± 0.008 a	0.017 ± 0.006 a
Total Nitrogen (mg/l)	1.77 ± 0.09 b	1.8 ± 0.22 b	1.78 ± 0.13 b	0.69 ± 0.05 a
Soluble Reactive Phosphorus (mg/l)	0.10 ± 0.11 a	0.06 ± 0.02 a	0.11 ± 0.05 a	0.05 ± 0.01 a
Total Phosphorus (mg/l)	0.25 ± 0.10 b	0.26 ± 0.04 b	0.32 ± 0.08 b	0.12 ± 0.01 a
Total Alkalinity (mg/l as $CaCO_3$)	154.6 ± 19.9 a	146.2 ± 5.3 a	147.7 ± 5.2 a	-
Chlorophyll-*a* (mg/m^3)	54.96 ± 8.08 b	66.06 ± 13.70 b	53.19 ± 13.41 b	24.21 ± 7.63 a
BOD_2 (mg/l)	9.84 ± 1.21 b	9.57 ± 0.90 b	9.69 ± 1.32 b	5.52 ± 0.44 a

ab: Variable means followed by the same letter are not significantly different (P > 0.05).

Table 4. Initial and final mean (± SD) soil nutrient concentrations in 1.67-ha shrimp ponds. Top 2.5 cm of pond sediment was collected for analysis.

Pond	Calcium (mg/kg)		Potassium (mg/kg)		Magnesium (mg/kg)	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*
VN6	1493.8 ± 318.8	2250.6 ± 644.2	683.6 ± 134.4	1294.3 ± 143.0	2081.7 ± 519.6	3451.0 ± 646.6
VN7	905.0 ± 33.64	1844.7 ± 468.9	640.1 ± 32.2	1166.3 ± 183.1	1808.4 ± 178.5	3149.6 ± 981.3
VN8	1396.0 ± 681.0	2253.5 ± 205.8	676.9 ± 72.8	1118.7 ± 115.9	1737.2 ± 380.5	2691.3 ± 506.5
VN10	1071.6 ± 146.4	1413.1 ± 430.0	691.9 ± 37.5	904.2 ± 141.5	2202.5 ± 513.8	2082.8 ± 271.5
VN11	1286.2 ± 525.7	1820.2 ± 669.7	700.6 ± 48.2	1094.3 ± 237.4	2001.7 ± 317.2	2587.4 ± 297.0
VN12	1336.0 ± 275.4	1862.1 ± 553.0	810.3 ± 31.9	1080.7 ± 124.8	2254.0 ± 171.9	2408.3 ± 326.1
VN13	1165.2 ± 176.9	2014.0 ± 430.5	739.9 ± 84.6	1136.9 ± 271.8	1871.0 ± 414.7	2702.7 ± 695.5
VN14	1248.8 ± 200.4	1722.2 ± 232.4	799.8 ± 68.9	1114.7 ± 142.2	2145.8 ± 212.0	2441.7 ± 299.4
VN15	1147.5 ± 255.0	1643.5 ± 263.8	738.9 ± 114.9	1146.5 ± 62.8	1921.5 ± 377.7	2965.3 ± 66.6
VN16	1286.2 ± 293.0	2052.7 ± 765.4	751.0 ± 38.7	1168.0 ± 174.0	2055.5 ± 123.9	2796.1 ± 442.7
VN17	1194.2 ± 161.6	1584.4 ± 118.5	788.4 ± 116.3	1267.1 ± 56.7	2069.8 ± 338.8	2981.1 ± 311.1
VN18	1306.2 ± 22.8	2116.9 ± 61.6	755.9 ± 111.4	1271.5 ± 83.5	2161.0 ± 462.4	2987.2 ± 330.3

Pond	Phosphorus (mg/kg)		Copper (mg/kg)		Iron (mg/kg)		Manganese (mg/kg)	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
VN6	73.5 ± 60.7	35.0 ± 12.8	1.2 ± 0.2	0.7 ± 0.5	34.9 ± 7.0	55.8 ± 6.3	371.4 ± 98.1	802.6 ± 164.3
VN7	77.0 ± 32.6	52.4 ± 24.2	1.6 ± 0.8	1.1 ± 0.8	41.1 ± 14.8	94.5 ± 28.0	195.5 ± 39.1	499.9 ± 136.2
VN8	123.7 ± 117.5	70.9 ± 66.5	1.7 ± 0.4	1.0 ± 0.7	43.2 ± 9.8	124.7 ± 23.3	254.1 ± 83.9	536.2 ± 126.1
VN10	85.4 ± 39.0	86.2 ± 46.5	2.4 ± 0.8	2.0 ± 1.0	51.3 ± 18.7	116.2 ± 14.2	223.7 ± 40.2	370.3 ± 103.8
VN11	114.9 ± 92.4	136.9 ± 158.3	1.8 ± 0.7	1.3 ± 0.8	49.4 ± 16.5	112.4 ± 22.4	341.2 ± 110.9	545.8 ± 278.5
VN12	99.6 ± 52.5	121.9 ± 142.9	1.3 ± 0.2	1.1 ± 0.5	37.1 ± 10.1	93.2 ± 34.0	421.1 ± 27.5	498.8 ± 61.3
VN13	112.2 ± 67.0	140.5 ± 183.0	1.5 ± 0.7	0.8 ± 0.7	33.5 ± 1.5	87.3 ± 42.5	332.8 ± 124.8	607.4 ± 226.1
VN14	73.6 ± 30.4	129.6 ± 118.0	1.4 ± 0.8	1.3 ± 1.0	55.1 ± 32.5	97.5 ± 38.9	326.1 ± 111.2	385.7 ± 97.1
VN15	115.5 ± 106.6	45.4 ± 15.7	1.8 ± 0.6	0.7 ± 0.5	49.2 ± 6.7	31.1 ± 14.1	271.6 ± 80.7	561.9 ± 104.3
VN16	78.5 ± 47.2	37.7 ± 10.2	1.8 ± 0.8	0.6 ± 0.6	55.7 ± 22.0	67.7 ± 39.1	288.6 ± 70.7	465.0 ± 39.1
VN17	81.3 ± 68.3	59.7 ± 47.9	1.7 ± 0.8	1.0 ± 0.7	46.7 ± 12.2	100.9 ± 24.9	319.0 ± 47.7	498.5 ± 92.3
VN18	96.5 ± 90.2	70.3 ± 39.2	1.4 ± 0.8	0.9 ± 0.2	57.5 ± 18.0	106.4 ± 41.5	260.3 ± 109.8	349.5 ± 107.6

were significant differences in nitrogen and phosphorus additions to ponds, there were no significant differences among treatments in nitrogen or phosphorus concentrations in water discharged from ponds.

Soil calcium, potassium, magnesium, iron, manganese, boron, sodium, and nitrogen concentrations were higher in the final soil sample (Table 4). Concentrations of phosphorus, copper, zinc, barium, cobalt, chromium, total phosphorus,

Table 4. Continued.

Pond	Zinc (mg/kg)		Boron (mg/kg)		Molybdium (mg/kg)		Aluminum (mg/kg)	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
VN6	4.4 ± 0.6	3.8 ± 0.4	15.1 ± 3.8	23.9 ± 2.7	1.8 ±0.4	2.2 ± 2.3	173.3 ± 13.2	66.4 ± 42.5
VN7	4.4 ± 0.6	5.7 ± 1.2	13.2 ± 0.8	21.8 ± 7.0	7.8 ± 10.5	1.9 ± 1.4	187.4 ± 49.6	123.2 ± 41.7
VN8	5.1 ± 0.8	6.0 ± 0.8	12.2 ± 2.9	16.5 ± 2.6	4.0 ± 4.1	1.6 ± 0.8	186.6 ± 31.9	122.7 ± 32.5
VN10	4.8 ± 0.5	5.3 ± 0.2	14.8 ± 1.9	14.3 ± 2.7	3.3 ± 2.8	1.4 ± 0.5	214.2 ± 52.7	185.1 ± 26.6
VN11	4.7 ± 0.5	5.7 ± 1.0	13.3 ± 0.9	18.0 ± 2.6	2.8 ± 2.0	1.4 ± 0.5	192.3 ± 38.0	146.3 ± 26.3
VN12	4.7 ± 0.9	5.5 ± 1.2	13.6 ± 0.3	16.9 ± 3.3	2.6 ± 1.4	1.2 ± 0.4	181.4 ± 33.7	134.3 ± 26.8
VN13	5.0 ± 0.7	5.0 ± 0.4	12.8 ± 2.0	18.6 ± 5.0	2.3 ± 1.0	1.3 ± 0.3	172.1 ± 7.0	112.9 ± 31.6
VN14	5.9 ± 2.8	5.8 ± 1.4	14.2 ± 0.8	15.7 ± 3.3	2.1 ± 1.0	1.3 ± 0.2	148.9 ± 37.4	184.2 ± 45.0
VN15	4.9 ± 1.0	4.5 ± 1.3	13.5 ± 1.9	21.2 ± 0.9	2.0 ± 0.7	1.3 ± 0.2	182.9 ± 19.4	119.4 ± 28.4
VN16	5.0 ± 0.6	4.9 ± 1.3	13.8 ± 0.1	21.3 ± 4.5	1.9 ± 0.6	1.1 ± 0.2	182.9 ± 35.4	88.1 ± 49.7
VN17	5.2 ± 1.2	5.8 ± 3.0	15.0 ± 3.2	21.2 ± 2.8	2.1 ± 1.0	1.1 ± 0.6	176.1 ± 27.5	117.7 ± 50.5
VN18	5.0 ± 1.4	5.2 ± 2.1	14.0 ± 3.5	20.1 ± 1.6	1.8 ± 0.6	1.1 ± 0.3	164.6 ± 33.8	109.6 ± 12.3

Pond	Barium (mg/kg)		Cobalt (mg/kg)		Chromium (mg/kg)		Lead (mg/kg)	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
VN6	2.9 ± 0.3	3.4 ± 0.6	0.9 ± 0.2	0.8 ± 0.3	0.6 ± 0.3	1.0 ± 0.9	2.4 ± 0.4	0.9 ± 0.0
VN7	2.7 ± 0.5	3.0 ± 0.5	0.8 ± 0.1	1.0 ± 0.5	0.4 ± 0.1	0.7 ± 0.4	2.4 ± 0.5	0.9 ± 0.0
VN8	2.2 ± 0.3	3.5 ± 0.3	0.9 ± 0.1	1.0 ± 0.2	0.5 ± 0.2	1.0 ± 0.5	2.3 ± 0.6	0.8 ± 0.1
VN10	2.2 ± 0.2	2.6 ± 0.6	0.9 ± 0.1	1.1 ± 0.1	0.6 ± 0.0	0.8 ± 0.5	3.1 ± 0.9	2.7 ± 3.1
VN11	2.3 ± 0.2	2.2 ± 0.5	1.0 ± 0.2	0.9 ± 0.0	0.7 ± 0.1	0.5 ± 0.5	2.6 ± 0.4	0.9 ± 0.0
VN12	2.5 ± 0.1	2.3 ± 0.1	1.1 ± 0.1	0.9 ± 0.2	0.8 ± 0.1	0.6 ± 0.4	2.4 ± 0.4	0.9 ± 0.0
VN13	2.6 ± 0.2	3.6 ± 1.2	1.1 ± 0.2	1.0 ± 0.2	0.6 ± 0.3	0.8 ± 0.4	2.4 ± 0.5	0.9 ± 0.0
VN14	2.3 ± 0.5	2.4 ± 0.8	1.0 ± 0.5	1.0 ± 0.1	0.6 ± 0.2	0.8 ± 0.3	2.7 ± 1.5	0.9 ± 0.0
VN15	3.0 ± 1.0	2.6 ± 0.4	1.0 ± 0.1	0.7 ± 0.2	0.6 ± 0.3	0.7 ± 0.2	2.5 ± 0.4	0.9 ± 0.0
VN16	2.8 ± 0.6	2.6 ± 0.4	0.9 ± 0.1	0.6 ± 0.2	0.6 ± 0.1	0.9 ± 0.3	2.5 ± 0.5	0.9 ± 0.0
VN17	2.8 ± 0.4	3.0 ± 0.6	0.9 ± 0.1	1.0 ± 0.4	0.6 ± 0.2	0.8 ± 0.2	2.4 ± 0.4	0.9 ± 0.0
VN18	2.8 ± 0.2	3.3 ± 0.2	0.9 ± 0.0	0.8 ± 0.1	0.7 ± 0.3	0.8 ± 0.1	2.6 ± 0.4	0.9 ± 0.0

Table 4. Continued.

Pond	Sodium (mg/kg)		Total Phosphorus (mg/kg)		Carbon (%)		Nitrogen (%)	
	Initial	*Final*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
VN6	7964.3 ± 3356.9	23014.5 ± 8028.4	1150.4 ± 151.6	1167.4 ± 109.3	1.2 ± 0.3	1.6 ± 0.4	0.1 ± 0.1	0.2 ± 0.0
VN7	6401.6 ± 338.8	19682.9 ± 7699.7	1113.9 ± 193.6	1220.8 ± 49.6	1.0 ± 0.4	1.5 ± 0.3	0.1 ± 0.1	0.2 ± 0.0
VN8	6977.8 ± 2268.1	18669.8 ± 4091.9	1262.1 ± 59.7	1269.4 ± 52.6	1.0 ± 0.2	1.5 ± 0.3	0.1 ± 0.0	0.2 ± 0.0
VN10	8758.8 ± 2329.9	11733.1 ± 2176.0	1077.5 ± 132.9	1007.0 ± 191.1	0.9 ± 0.2	1.0 ± 0.6	0.1 ± 0.0	0.2 ± 0.1
VN11	8185.0 ± 3067.8	14904.1 ± 3811.1	1245.1 ± 157.1	1432.2 ± 416.8	1.1 ± 0.5	1.3 ± 0.4	0.1 ± 0.1	0.2 ± 0.1
VN12	8863.8 ± 1457.3	14604.5 ± 2624.8	1337.4 ± 23.4	1347.2 ± 270.4	1.2 ± 0.4	1.3 ± 0.4	0.1 ± 0.0	0.2 ± 0.0
VN13	6843.4 ± 1164.5	17610.1 ± 5867.9	1315.6 ± 36.0	1337.4 ± 204.4	1.3 ± 0.6	1.3 ± 0.5	0.1 ± 0.1	0.2 ± 0.0
VN14	8923.2 ± 1219.3	15023.7 ± 3506.3	1359.3 ± 99.5	1194.1 ± 88.2	1.5 ± 0.4	1.0 ± 0.5	0.2 ± 0.0	0.2 ± 0.1
VN15	6625.1 ± 2141.6	16786.5 ± 209.8	1223.2 ± 146.0	1147.9 ± 49.6	1.1 ± 0.5	1.7 ± 0.4	0.1 ± 0.0	0.2 ± 0.0
VN16	7467.0 ± 792.3	17674.6 ± 3388.1	1179.5 ± 120.7	1194.1 ± 67.7	1.1 ± 0.4	1.6 ± 0.2	0.1 ± 0.0	0.2 ± 0.0
VN17	8320.8 ± 2001.5	17865.3 ± 2194.1	1237.8 ± 97.9	1242.7 ± 21.0	1.2 ± 0.4	1.4 ± 0.4	0.1 ± 0.0	0.2 ± 0.0
VN18	7848.3 ± 2072.8	19418.3 ± 1894.4	1242.7 ± 116.3	1352.0 ± 147.3	1.2 ± 0.5	1.3 ± 0.1	0.1 ± 0.1	0.2 ± 0.0

and carbon were similar in initial and final sediment samples (Table 4). Molybdium, aluminum, and lead concentrations in pond sediments were lower in the final sample (Table 4). Particle size distribution of pond sediments showed a predominance of clay (48.7%), followed by silt (39.7%), and then sand (11.6 %) (Table 5).

Discussion

Taura Syndrome is endemic in southern Honduras and observed shrimp survivals in this experiment were typical for animals exposed to Taura Syndrome (Lightner and Redman, 1994; Brock et al., 1995). While shrimp farmers have adjusted their management strategy to compensate for this mortality by stocking up to four times the target stocking rate, the economic impact of this strategy has become significant.

Dietary protein level did not affect shrimp yields. Results of this study confirm results of previous studies that evaluated the effect of dietary protein on shrimp growth and yield in semi-intensive culture. Teichert-Coddington and Rodriguez (1995a) tested a 20% and 40% protein diet in ponds stocked with 5 or 11 *P. vannamei*/ha. Shrimp yield and growth were similar for the high and low protein feeds within each stocking rate (Teichert-Coddington and Rodriguez, 1995a). In another study, provision of a 29% or 37% protein feed did not significantly affect shrimp yields from semi-intensive culture ponds stocked with 4-8 *P. vannamei*/ha (Teichert-Coddington and Arrue, 1988).

Increased feeding rate (as a percentage of the feeding curve) with the 20% protein feed did result in significantly greater shrimp yield. However, neither final individual shrimp weight nor survival differed significantly between treatments. It is unlikely that treatment differences were responsible for the significant difference in yields observed between the two feeding rates for the 20% protein feed but rather they may have been responsible for shrimp survival. Although no significant differences in survival were detected, observed survival in the 20% protein-50% feed curve treatment was 5.2% lower than in the 20% protein-75% feed curve treatment. Given the absence of a difference in mean final weight, survival alone could account for the observed difference in yields. Similar growth curves for shrimp in both treatments provided further evidence of a lack of treatment differences.

Table 5. Particle size distribution, cation exchange capacity (CEC), and sulfur concentration in top 2.5 cm of shrimp pond sediment.

Pond	Sand (%)	Silt (%)	Clay (%)	CEC (meq/100 g)	Sulfur (%)
VN6	6.5	44.02	49.48	32.45	0.15
VN7	9.5	39.98	50.52	21.92	0.01
VN8	10.5	41.38	48.12	27.69	0.08
VN10	14.4	44.32	41.28	25.73	0.06
VN11	13.4	39.28	47.32	23.33	0.13
VN12	7.2	43.04	49.76	25.77	0.15
VN13	5.9	43.02	51.08	22.76	0.17
VN14	6.3	41.94	51.76	27.19	0.14
VN15	32.5	26.98	40.52	20.02	0.08
VN16	17.4	35.24	47.36	24.98	0.19
VN17	11.6	36.40	52.00	56.49	0.16
VN18	4.2	41.04	54.76	29.67	0.19

Shrimp yields observed in the present research were similar to dry season yields reported by Teichert-Coddington and Rodriguez (1995a and 1995b) and Teichert-Coddington et al. (1996) for 95- to 112-day culture periods. In the present trial, shrimp appeared to have grown little since day 66, and ponds were harvested after 87 days. Evaluation of data from Teichert-Coddington and Rodriguez (1995a and 1995b) and from Teichert-Coddington et al. (1996) indicated that little shrimp growth occurs after 11 to 12 weeks of culture during the dry season in Honduras. Continuation of culture beyond 12 weeks likely results in reduced profit because increased costs for feed and water pumping are not offset by increased production.

Feed conversion ratios in the present experiment were low, which indicated the following:

1) efficient feed management;
2) formulated feed only served to supplement natural productivity as a source of nutrients for shrimp growth; and
3) ponds were harvested before shrimp growth had ceased.

In fact, FCRs observed in this study were the lowest reported for shrimp research during the dry-season in Honduras. Dry-season FCRs reported from other research in Honduras ranged from 1.3 to 5.2, with a mean of 3.2 (Teichert-Coddington et al., 1991; Teichert-Coddington and Rodriguez, 1995a and b; Teichert-Coddington et al., 1996). One factor that contributed to the high value of the reported FCRs was that feed was applied at 100% of the feed curve (Teichert-Coddington et al., 1991; Teichert-Coddington and Rodriguez, 1995a and 1995b), compared with application of 50 and 75% of the feed curve in the present experiment. Another factor that affected reported FCRs was continued feeding of shrimp during the 14- to 16-week dry-season culture period despite insignificant shrimp growth beyond weeks 11 and 12 (Teichert-Coddington and Rodriguez, 1995a and 1995b).

An additional benefit of reduced FCRs is that less nitrogen and phosphorus are added to ponds, thereby reducing the potential pollution impact of pond effluents. Significantly greater quantities of nitrogen and phosphorus were added to ponds as feed in the 20% protein-75% feed rate treatment. However, significant differences in water quality variables of discharge water were not observed among treatments possibly because the differences among treatments in terms of total quantity of feed applied were not large enough for water quality differences to be manifested.

Although shrimp yield was not significantly greater and FCR was significantly greater for the 20% protein feed-75% feed rate treatment, this treatment resulted in the highest income from the sale of product. Increasing dietary protein from 20 to 30% was not justified either in terms of production or economics. Partial budget analysis showed an increase in net profit of $313/ha if the 20% protein feed-75% feed rate was used instead of the 20% protein feed-50% feed rate. However, because shrimp survival has been so variable and does affect yield, additional research on reduced feed rates is necessary before the 75% feed rate is adopted over the 50% feed rate.

Anticipated Benefits

Results of this experiment show that a 30% protein feed is not necessary for dry-season production of *P. vannamei* in semi-intensive culture in Honduras. Feeding a 20% protein feed at 75% of the feed curve does not result in statistically greater yield than applying the same feed at 50% of the feed curve; however, it does result in higher income. This was a result of slightly greater shrimp survival, so additional research is needed to confirm or reject this 50% feed rate. Use of the lower feed rate would result in a significantly lower need to add nitrogen and phosphorus to ponds.

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Literature Cited

Brock, J.A., R. Gose, D.V. Lightner, and K. Hasson, 1995. An overview on Taura Syndrome, an important disease of farmed *Penaeus vannamei*. In: C.L. Browdy and J.S. Hopkins (Editors), Swimming Through Troubled Water. Proceedings of the Special Session on Shrimp Farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, LA, pp. 84-94.

Grasshoff, K., M. Ehrhardt, and K. Kremling. 1983. Methods of seawater analysis. Verlag Chemie, Weinheim, Germany, 419 pp.

Haycock, K., J. Roth, J. Gagnon, W.R. Finzer, and C. Soper, 1992. StatView 4.0 (software). Abacus Concepts, Inc., Berkeley, CA.

Kay, R. D., 1981. Farm management. McGraw-Hill Book Company, New York, 370 pp.

Lightner, D.V. and R.M. Redman, 1994. Histopathology, histochemistry and ultrastructural studies of Taura Syndrome, a putative toxicity syndrome of penaeid shrimp (abstract). In: Book of Abstracts, World Aquaculture '94, 14-18 January , 1994, New Orleans, LA. World Aquaculture Society, Baton Rouge, LA, p. 227.

Munsiri, P., C.E. Boyd, and B.F. Hajek, 1995. Physical and chemical characteristics of pond bottom soil profiles in ponds at Auburn, Alabama, USA, and a proposed system for describing pond soil horizons. Journal of the World Aquaculture Society, 26:346-377.

Parsons, T.R., Y. Maita, and C.M. Lalli, 1992. A manual of chemical and biological methods for seawater analysis. Pergamon Press, New York, 144 pp.

Teichert-Coddington, D.R. and M. Arrue, 1988. Effectos de dietas de proteinas y densidades de siembra sobre la produccion de *Penaeus vannamei* en estanques de tierra. Revista Latinoamericana de Acuicultura, 35:29-33.

Teichert-Coddington, D.R., B.W. Green, and R.W. Parkman, 1991. Substitution of chicken litter for feed in production of penaeid shrimp in Honduras. Progressive Fish-Culturist, 53:150-156.

Teichert-Coddington, D.R. and R. Rodriguez, 1995a. Semi-intensive commercial grow-out of *Penaeus vannamei* fed diets containing differing levels of crude protein during wet and dry seasons in Honduras. Journal of the World Aquaculture Society, 26: 72-79.

Teichert-Coddington, D.R. and R. Rodriguez, 1995b. Inorganic fertilization and feed reduction in commercial production of *Penaeus vannamei* during wet and dry seasons in Honduras. In: H. Egna, J. Bowman, B. Goetze and N. Weidner (Editors), Twelfth Annual Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 136-146.

Teichert-Coddington, D.R., W. Toyufuku, J. Harvin, and R. Rodriguez, 1996. Relationships among stocking density, survival and yield in ponds affected by the Taura Syndrome during wet and dry seasons in Honduras. In: H. Egna, B. Goetze, D. Burke, M. McNamara and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 85-94.

Estuarine Water Quality

Interim Work Plan, Honduras Study 2

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Introduction

A baseline of information has been established on selected chemical, biological, and physical characteristics of water at points along major shrimp producing estuaries in southern Honduras (Teichert-Coddington et al., 1996). The objective of this study was to continue to monitor the estuarine water quality in order to detect trends over time and evaluate the impact of shrimp farming on the water quality.

Materials and Methods

Water samples were collected every one to two weeks from at least 12 sampling sites distributed over six estuaries in the shrimp farming area of southern Honduras. Samples were collected at intake pumps of shrimp farms at about the middle of a daily pumping cycle. An additional sample site on the Choluteca River serves as a reference point. Water was analyzed for total settleable solids (APHA et al., 1992), total ammonia nitrogen (Parsons et al., 1992), filterable reactive phosphate (Grasshoff et al., 1983), chlorophyll-*a* (Parsons et al., 1992), total alkalinity by titration to 4.5 pH endpoint, salinity, and BOD_7. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation (Grasshoff et al., 1983). Data were summarized by estuarine type, location, season, month, and year.

Results and Discussion

Data collection and analyses are incomplete. A preliminary analysis of total nitrogen was completed for El Pedregal estuary, which supports over 2000 ha of shrimp ponds. Total nitrogen concentrations determined since the project began in 1993 were summarized by month and compared with total nitrogen input by feed during the same period (Figure 1). Total nitrogen concentrations have not increased with time, primarily because runoff from rainfall flushes the estuaries yearly. Nitrogen input as feed was greatest during the rainy season because shrimp growth is always two to three times greater during this season compared with the dry season (Teichert-Coddington et al., 1994). However, there was no accumulation of nitrogen from heavy feeding because of flushing by runoff. On the other hand, nitrogen concentrations in the estuary tended to increase in the dry season during periods of relatively light feeding because freshwater input was insignificant and exchange with bay water was low. Farm management to minimize effluents during the dry season is critical for preventing eutrophication of estuaries and unsustainable shrimp culture conditions.

Literature Cited

American Public Health Association (APHA), 1992. Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington, D.C., 874 pp.

Grasshoff, K., M. Ehrhardt, K. Kremling, and T. Almgren, 1983. Methods of seawater analysis. Verlag Chemie, Weinheim, Germany, 419 pp.

Parsons, T.R., Y. Maita and C.M. Lalli, 1992. A Manual of Chemical and Biological

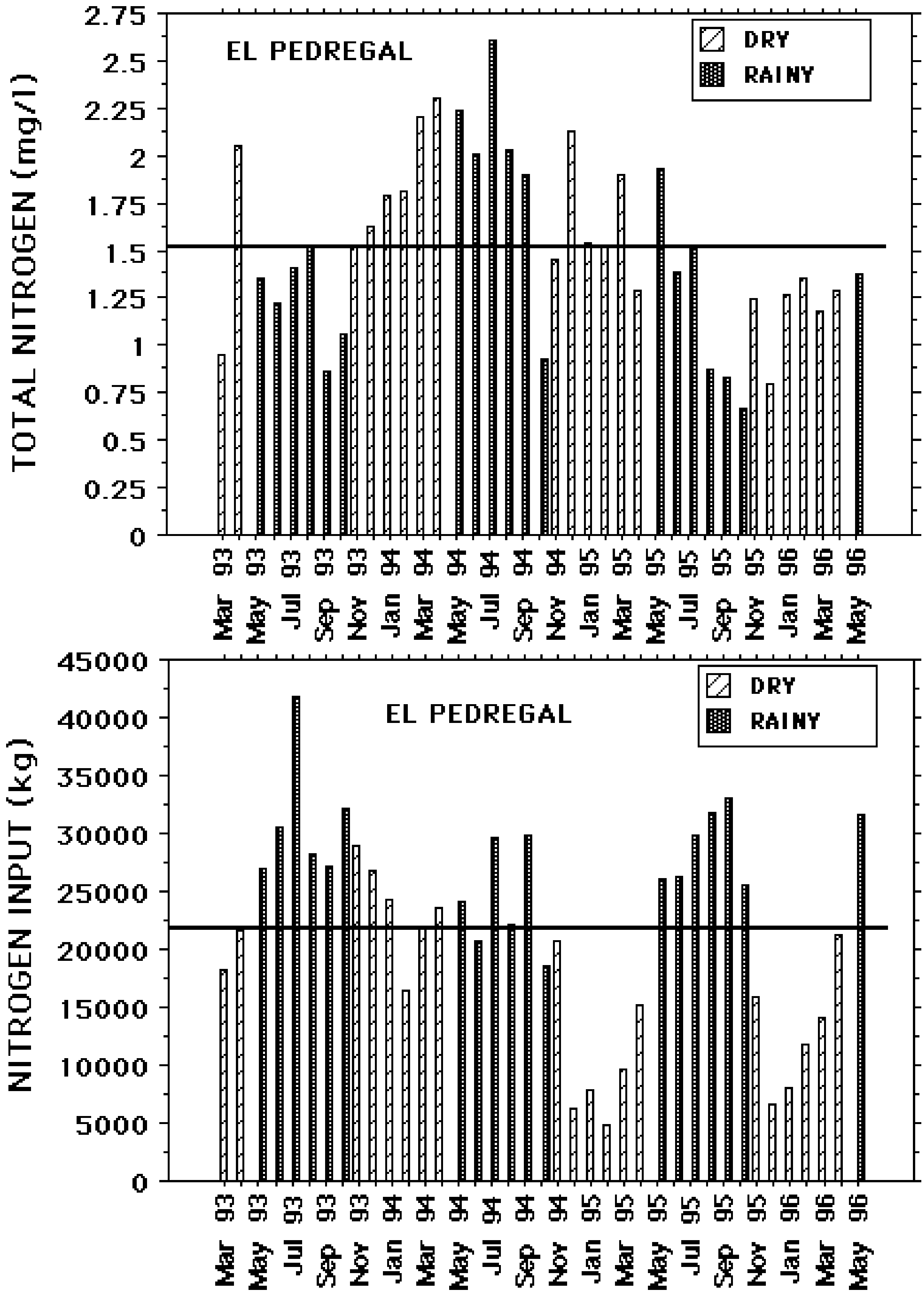

Figure 1. Mean monthly total nitrogen concentrations and nitrogen input as feed in El Pedregal estuary from March 1993 to May 1996. The horizontal black line is the mean during the sampling period.

Methods for Seawater Analysis. Pergamon Press, New York, USA, 144 pp.

Teichert-Coddington, D.R., D. Martinez, and E. Ramírez, 1996. Characterization of shrimp farm effluents in Honduras and chemical budgets of selected nutrients. In: H. Egna, B. Goetze, D. Burke, M. McNamara and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 70-84.

Teichert-Coddington, D.R., R. Rodriguez, and W. Toyofuku, 1994. Cause of cyclical variation in Honduran shrimp production. World Aquaculture, 25(1):57-61.

Sex Reversal of Tilapia: 17α-Methyltestosterone Dose Rate by Environment and Efficacy of Bull Testes

Interim Work Plan, Honduras, Study 4

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Introduction

Sex reversal of newly hatched tilapia generally is accomplished via oral administration of 17α-methyltestosterone (MT), which has been incorporated into a starter fish feed at 60 mg MT/kg feed (Popma and Green, 1990). Although the use of the 60 mg MT/kg feed dose consistently yields populations comprised of less than 5% females (i.e., > 95% males), this has not been shown to be the optimal dose. Other investigators have reported sex reversal of tilapia at dose rates less than 60 mg MT/kg feed (Guerrero, 1975; Tayamen and Shelton, 1978; McGeachin et al., 1987; Jo et al., 1988; Varadaraj and Pandian, 1989); however, results from some of these studies are inconsistent, and it is difficult to separate treatment environment effects. Thus, it is necessary to identify the optimal dose of MT for consistent, successful sex reversal in a variety of treatment environments.

Naturally occurring sources of testosterone may be an alternative to using a synthetic androgen, which also is an anabolic steroid, for tilapia sex reversal. Haylor and Pascual (1991) reported successful tilapia sex reversal using ram testes as a source of dietary testosterone. Bull testes are a by-product of the beef industry in the US and are a potential source of dietary testosterone for tilapia sex reversal.

The objectives of this research were to:

1) determine the efficacy of different dosage rates of MT for sex reversal of fish treated in different environments; and
2) evaluate the potential of freeze-dried bull testes as a dietary source of testosterone for tilapia sex reversal.

Materials and Methods

Newly hatched Nile tilapia (*Oreochromis niloticus*) were stocked at 8 fry/l into 80-l glass aquaria located inside a hatchery building or into hapas (45-l volume) suspended in 20-m^3 outdoor concrete tanks located at the Fisheries Research Unit, Alabama Agricultural Experiment Station, Auburn University, AL. Fry were stocked on 1 August 1995 and harvested after a 28-d treatment period. Subsamples of fry from each treatment unit were transferred to hapas suspended in 20-m^3 outdoor concrete tanks for nursery rearing to approximately 5-g size. Once fingerlings attained an average weight of 5 grams, they were sacrificed, the gonads were excised, and sex was determined according to the aceto-carmine squash method (Guerrero and Shelton, 1974).

Trout chow (42% protein) was the carrier for MT, which was incorporated into the feed at 0, 10, 20, 30 or 40 mg MT/kg of feed. The appropriate quantity of MT was dissolved in 500 ml of 95% ethanol/kg feed, and mixed with the powdered feed. Ethanol only was mixed with feed for the 0 mg MT/kg feed treatment. Ethanol was evaporated from the alcohol-feed mixture, and the dried feed was refrigerated until use. Fry in each treatment were fed at 20% body weight during week one; the daily ration was divided into four meals. Feed rate was decreased by 2.5%/wk during weeks two to four and adjusted weekly based on results of weekly population samples.

Frozen bull testes were obtained from a meat packing plant in Montgomery, AL. Individual testes were skinned, sliced, freeze-dried, ground, and mixed with trout chow either in a 1:1 or 1:3 freeze-dried testes:trout chow ratio. Mixed feed was refrigerated until feeding. The concentration of testosterone per gram of freeze-dried testes was determined by radioimmuno assay (Rahe, personal communication).

Results

The use of freeze-dried bull testes (BT) as a source of testosterone was not effective in producing tilapia populations of 95% or greater males. The percentage of males (54%) in populations fed a ration containing 25% BT did not differ from non-treated populations (52.4%). The percentage males (64.8%) obtained when BT composed half of the ration was significantly greater than non-treated populations; however, the percentage males obtained was too low for such a ration to be considered practical for the production of male tilapia.

Indoor and outdoor treatments did not affect the ability of 17α-methyltestosterone to alter the sex ratio of tilapia. Greater than 97% male populations were obtained at dose rates of 15, 30, 45 and 60 mg MT /kg of diet when fish were treated in indoor aquaria or outdoor hapas.

After the 28-d MT treatment period, fry mean total lengths ranged from 32.8 to 39.6 mm and 40.7 to 44.3 mm for fry treated in aquaria (indoors) and hapas (outdoors), respectively. Average respective final weight ranges were 0.7 to 1.0 and 1.2 to 1.9 g/fry. Fry survival in both environments was low and ranged from 16.7 to 27.7% and 25.7 to 43.6% in aquaria (indoors) and hapas (outdoors), respectively.

Fry fed feed containing bull testes were 55.6 and 59.7 mm total length for 1:1 and 1:3 ratio feeds, respectively, following the 28-d treatment period. Mean final weights were 2.0 and 0.7 g/fry for 1:1 and 1:3 ratio feeds, respectively, which undoubtedly reflected the difference in respective survival during treatment (28.3 versus 69.2%).

Discussion

Popma and Green (1990) discussed how the presence of 3 to 5% females in tilapia production ponds can result in excessive reproduction and reduced growth. The testosterone level of the freeze-dried bull testes was found to be 11.4 µg/g (Rahe, personal communication). When mixed half and half with the commercial ration, the effective hormone dose was reduced to approximately 5.7 mg/kg of diet. If given as the sole component of the ration, BT containing 11.4 µg/g may give an acceptable percentage of males. Jay-Yoon et al. (1988) obtained 97% male *O. niloticus* populations feeding 10 mg of 17α-methyltestosterone/kg of ration. Pandian and Varadaraj (1988) were able to produce a 100% male population of *O. mossambicus* using 5 mg of 17α-methyltestosterone/kg of diet.

Anticipated Benefits

Bull testes were demonstrated to be an ineffective source of testosterone for sex reversal of tilapia. Methyltestosterone appeared to be efficacious at all dose rates tested; however, the dose-response evaluation was complicated because of low survival. Treatment environment also does not affect the efficacy of 17α-methyltestosterone treatment for sex reversal.

Literature Cited

Guerrero, R.D., 1975. Use of androgens for the production of all-male *Tilapia aurea*

(Steindachner). Transactions of American Fisheries Society, 104:342-348.

Guerrero, R.D. and W.L. Shelton, 1974. An aceto-carmine squash method for sexing juvenile fishes. Progressive Fish Culturist, 36:56.

Haylor, G.S. and A.B. Pascual, 1991. Effect of using ram testes in a fry diet for *Oreochromis niloticus* (L.) on growth, survival and resultant phenotypic sex ratio. Aquaculture and Fisheries Management, 22:265-268.

Jo, J.-Y., R.O. Smitherman, and L.L. Behrends, 1988. Effects of dietary 17α-methyltestosterone on sex reversal and growth of *Oreochromis aureus*. In: R.S.V. Pullin, T. Bhukaswan, K. Tonguthai, and J.L. Maclean (Editors), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 203-207.

McGeachin, R.B., E.H. Robinson, and W.H. Neil, 1987. Effect of feeding high levels of androgens on the sex ratio of *Oreochromis aureus*. Aquaculture, 61:317-321.

Pandian, T.J. and K. Varadaraj, 1988. Techniques for producing all-male and all-triploid *Oreochromis mossambicus*. In: R.S.V. Pullin, T. Bhukaswan, K. Tonguthai, and J.L. Maclean (Editors), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Popma, T.J. and B.W. Green, 1990. Sex reversal of tilapia in earthen ponds. Research and Development Series No. 35. International Center for Aquaculture, Alabama Agricultural Experiment Station, Auburn University, AL, USA.

Rahe, personal communication.

Tayamen, M.M. and W.L. Shelton, 1978. Inducement of sex reversal in *Sarotherodon niloticus* (Linnaeus). Aquaculture, 14:349-354.

Varadaraj, K. and T.J. Pandian. 1989. Monosex male broods of *Oreochromis mossambicus* produced through artificial sex reversal with 17α-methyl-4 androsten-17β-ol-3-one. Current Trends in Life Science, 15:169-173.

East Africa

Currently, sex reversal of tilapia requires the daily application of a medicated feed to hapas or aquaria. An alternative approach was tested by Oregon State University researchers who experimented with a short-term immersion procedure for the masculinization of Nile tilapia (*Oreochromis niloticus*) using two synthetic androgens—17α-methyltestosterone and 17α-methyldihydrotestosterone. Immersions of Nile tilapia in methyldihydrotestosterone at 100 mg/l and methyltestosterone at 500 or 100 mg/l were not successful; however, tilapia immersed in 500 mg/l methyldihydrotestosterone may provide a practical alternative to the use of steroid-treated feed. This short-term immersion technique, when compared with current techniques for steroid-induced sex inversion of tilapia, shortens the hormone treatment period as well as reduces the risk of worker exposure to anabolic steroids.

Previous research has concluded that sub-optimal storage of hormones and hormone treated feed can greatly affect feed efficiency. PD/A CRSP researchers at Auburn University explored how storage conditions affect methyltestosterone-treated feed in terms of fish growth and sex reversal. Feed stored for extended periods of time at ambient tropical temperatures before use was compared with feed stored under refrigeration. Storage conditions did not affect growth, survival, feed conversion efficiency, or sex reversal success of *Oreochromis niloticus* fry fed a hormone prepared diet of 60 mg MT/kg for 28 days.

Fish farmers have reported red tilapia, a synthetic breed derived from *O. niloticus*, *O. aureus*, and *O. mossambicus*, to be more marketable than Nile tilapia. Hence, researchers at Auburn University, conducted an experiment in which they compared the reproductive efficiency, fry growth, survival, feed conversion, and success of sex reversal of Nile tilapia and red tilapia. Red tilapia fecundity was similar to the fecundity of Nile tilapia, and broodstock survival, fry per kg female, and overall numbers of fry produced were comparable. Fry production in both cases increased over time; however, the increase was not correlated with male:female weight ratio, broodstock condition, or female weight. Increased fry production from trial to trial may have been due to decreased territorial conflicts resulting from an already established social hierarchy during previous trials.

A series of experiments designed to evaluate alternative lime requirement determination methods in laboratory microcosms was extended to include the use of artificial enclosures or "isolation columns." Artificial enclosures were investigated as in-pond test units for liming studies. The results obtained from this method were compared with results obtained from laboratory microcosms. Noticeable differences in alkalinity trends in both limed and unlimed microcosms as well as in pond enclosures were detected. Significant differences were observed among all day-28 alkalinities except those in limed microcosms and limed isolation columns. This suggests that results in either the isolation columns, the microcosms, or both may not be representative of the effects of liming in real ponds. Further testing of in-pond enclosures is required. If enclosures that are consistently reliable can be developed, they may be useful for testing a number of different kinds of treatments within a given pond. The use of in-pond enclosures could lead to decreased variability among experimental units and reductions in the amounts of pond space, time, and other costs required to conduct pond-based research.

Pond bottom soils play an important role in determining pond productivity. As part of the CRSP effort to select a new prime site in Africa, soil samples were collected from five potential PD/A CRSP research sites in East Africa during site evaluation visits in 1994 and 1995. Nine soil samples were characterized according to their physical and chemical composition at Oregon State University. Results of the soil characterizations supplemented other information used to evaluate and select the new site for PD/A CRSP research in Africa.

After the PD/A CRSP lost its site at Rwasave, Rwanda, in 1994 due to civil war, a site selection team was appointed to develop a site selection strategy. Fifteen site evaluation criteria were defined with assistance from the Management Entity (ME) and the Technical Committee (TC), and USAID site selection criteria were incorporated into the evaluation process. PD/A CRSP researchers from Auburn University and Oregon State University visited several potential sites. After evaluating the major sites visited, the committee recommended to the Management Entity and Technical Committee that the Sagana Fish Culture Farm in Kenya be selected as the new Africa site.

Scientists at the University of Arkansas at Pine Bluff developed a mathematical programming model which used survey data from Rwanda to determine farm plans that maximize returns to a representative Rwandan farm family's resources. Study results indicated that the land holding of both individually- and cooperatively-managed farms were too low to meet the minimum nutritional needs of a family—a finding of importance for government policy making. Nevertheless, model results indicated that fish production was a profitable enterprise for subsistence farmers in Rwanda and that they competed well for scarce land resources. Various scenarios were explored. If fingerlings were sold, fish production was the optimal cash enterprise across most regions throughout the year. At a low level of willingness to incur risk, farmers selected as the optimal product mix soybeans and sweet potato production to meet household nutritional requirements and fish production as the principal cash crop. However, even without fingerling sales, fish production was selected over cabbage production. Only if fingerlings could not be sold, and if a higher level of risk was acceptable, cabbage production was preferred over fish production.

Masculinization of Tilapia through Immersion in 17α-Methyltestosterone or 17α-Methyldihydrotestosterone

Interim Work Plan, Africa Study 2

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Introduction

All-male populations are used in tilapia aquaculture because the culture of mixed-sex populations often results in precocious maturation and early reproduction (Mires, 1995). Early maturation shunts energy to gonadal rather than somatic growth. In addition, reproduction in ponds may lead to the harvest of many unmarketable fry. Individuals in mono-sex populations have increased somatic growth rate due to the avoidance of energy losses associated with gonadal development and reproduction. Furthermore, all-male tilapia populations are desirable because males achieve a larger final size than females (MacIntosh and Little, 1995).

One of the most common techniques for producing mono-sex populations is steroid-induced sex inversion (Hunter and Donalsdon, 1983). This involves administering synthetic androgens or estrogens to differentiating fry. The steroids act as sex-inversion agents by functionally masculinizing or feminizing individuals in the population. Several methods of steroid administration are possible, including injection, feeding of steroid, and immersion of fry in steroid solutions. Due to their non-invasive nature, the latter two are the most practical for application to aquaculture.

Use of steroid-treated feeds for the production of all-male populations is widespread in tilapia aquaculture (MacIntosh and Little, 1995).

Conversely, use of immersion techniques is not fully developed for practical usage. Torrans et al. (1988) successfully masculinized blue tilapia (*Oreochromis aureus*) using a long-term, continuous immersion in the synthetic androgen mibolerone (Mb). Optimum conditions for treatment were a five-week immersion period ([Mb]=600 mg/l H_2O) with steroid solutions replaced weekly. Pandian and Varadaraj (1987) masculinized Mozambique tilapia *(O. mossambicus)* by immersion in 17α-methyl-5-androsten-3β-17β-diol (5 or 10 mg/l). The immersion period lasted 10 days, beginning at 10 days post-fertilization. Although the authors reported 100% masculinization, detailed information regarding temperature, type of culture system used, fish density, and frequency of water exchange during the immersion period was not included.

A potential problem encountered when developing new methods for steroid-induced masculinization is paradoxical feminization, which results in the inadvertent production of feminized rather than masculinized populations. This phenomenon is caused by the aromatization of the synthetic androgen to a feminizing, estrogenic compound (Piferrer and Donaldson, 1991). Paradoxical feminization can be avoided by use of nonaromatizable androgens (Piferrer and Donaldson, 1991).

The objective of this research was to develop a short term immersion procedure for the masculinization of Nile tilapia (*O. niloticus*). Two synthetic androgens were tested, 17α-methyltestosterone (MT; 17α-methyl-4-androsten-3-one) and 17α-methyldihydrotestosterone (MDHT; 17α-methylandrostan-17β-ol-3-one). Methyldihydrotestosterone is a 17α-methylated nonaromatizable derivative of dihydrotestosterone. Methyltestosterone is one of the most commonly used sex-inverting agents but is susceptible to aromatization and has been associated with paradoxical feminization in chinook salmon (*Oncorhynchus tshawytscha*) (Piferrer and Donaldson, 1991).

Materials and Methods

Steroids were obtained from Sigma Chemical Company (St. Louis, MO) and stored in stock solutions of HPLC-grade methanol (10 mg/ml). Breeding families (one male to three females) were placed in 208-l aquaria. The temperature was maintained at 28-30°C. Breeding activity was monitored daily. Once breeding occurred between the male and one female, all fish were removed except for the brooding female, which was left to incubate the progeny. At 10 days post-fertilization (DPF), fry were removed from the female and randomly assigned to experimental groups (n = 100/group). Groups of fry were housed in 3.8-l glass jars with 3-l of fresh water. The water was maintained at 28 ± 2°C under constant aeration. Treatment consisted of a three-hour immersion on 10 and again on 13 DPF. After immersion, the fry were collected and placed in new jars that contained fresh water. For each immersion treatment, steroid was evaporated under N_2 (g) and delivered in 0.5 ml of ethanol. Steroid was allowed to mix by aeration for 30 min before addition of fry. Fry were immersed in MT or MDHT at 100 or 500 mg/l (MT-100, MT-500, MDHT-100, MDHT-500). Control groups included the following: immersion in water and ethanol vehicle (ethanol group), an immersion in water alone (control group), and water immersion followed by feeding of MT-treated diet (60 mg/kg) from 10 to 30 DPF. The MT-treated diet was made by dissolving steroid (30 mg) in 250 ml of 100% ethanol. The steroid solution was mixed with a commercial flake feed and allowed to dry before use. Other groups were fed commercial flake feed. Throughout the experiment, fry were fed to satiation 3-5 times daily.

The first experiment was repeated (experiment 2) with omission of the dietary MT control group. In experiment 1, the groups were held in the jars (3.8 l) until the end of the feeding treatment period (30 DPF). In experiment 2, fish were removed from the 3.8-l jars immediately following the 13 DPF immersion. Groups in both experiments were transferred to 20-l chambers for grow out in a recirculating system. Water temperature in the grow-out system was maintained at 28 ± 2°C. At 100 DPF, sex ratios were determined by examination of *in situ* (40X) and squash (100X) preparations after aceto-iron hematoxylin (Wittman, 1962) staining. Standard length and body weight of sampled fish was recorded in experiment 2.

Sex ratio data were analyzed using the chi-square test ($\alpha < 0.05$; Zar, 1984). The control and ethanol groups were not significantly different and were pooled for comparison to other groups. Mortality data were analyzed using the chi-square test ($\alpha < 0.05$; Zar, 1984). Length and weight data were

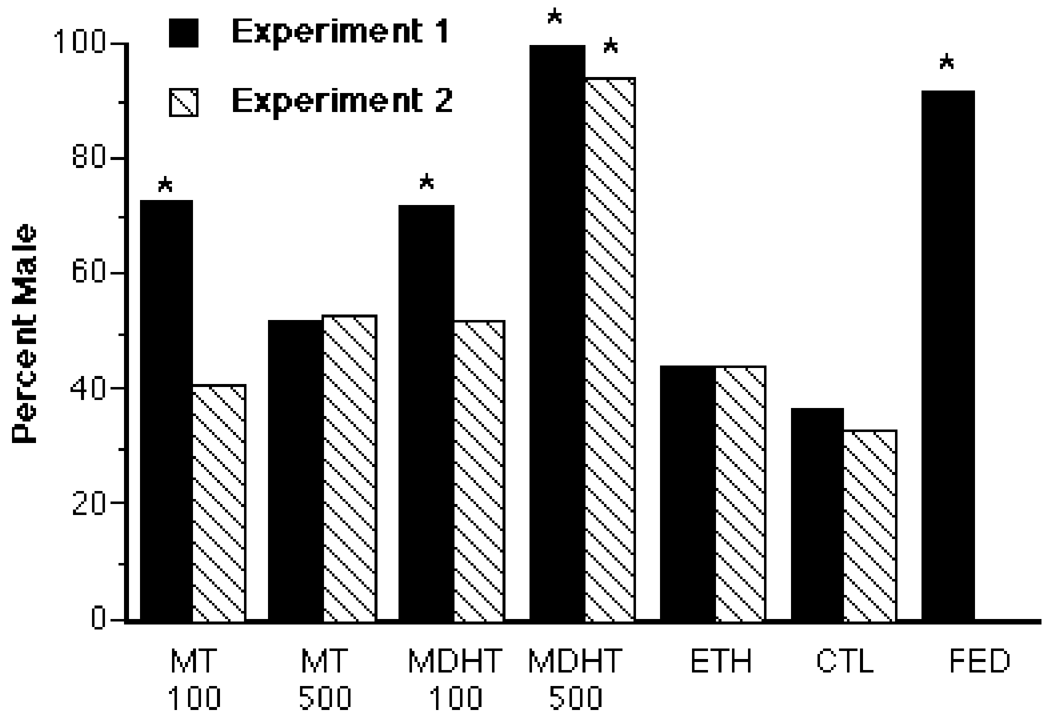

Figure 1. Percent males in each group for experiments 1 and 2. Group designations are as follows: immersion treatment in 100 or 500 mg 17α-methyltestosterone/l (MT 100, MT 500), immersion in 100 or 500 mg methyldihydrotestosterone/l (MDHT 100, MDHT 500), immersion in ethanol vehicle (ETH), immersion in water alone (CTL), and methyltestosterone feeding treatment (FED) from 10-30 DPF (60 mg/kg feed). Asterisks indicate significant (from chi square test; $\alpha \leq 0.05$) differences in proportion of males from the pooled control (ETH and CTL) group. Sample sizes ranged from 19 to 51 individuals.

not analyzed statistically, since these data were recorded for experiment 2 only.

Results

Immersion in MDHT at 500 mg/l resulted in 100 (experiment 1) and 94 (experiment 2) percent male populations (Figure 1). In experiment 1, MT and MDHT immersions at 100 mg/l resulted in significant skewing of the sex ratio toward males (73 and 72 percent male, respectively). However, in experiment 2, the proportion of males in these treatments was not significantly different from controls. Methyltestosterone at 500 mg/l had no masculinizing effect in either experiment. The MT feeding treatment resulted in 92 percent males.

Immersion treatment did not significantly affect mortality in either experiment (Table 1). High mortality was seen in the control group from experiment 1; this was associated with anoxic conditions caused by a clogged inlet during the grow-out period. The MT-500 group in experiment 2 suffered higher mortality due to cannibalization by an adult fish that jumped from an adjoining tank. Average final length and weight of fish were similar among treatments (Table 2).

Discussion

Immersion of Nile tilapia on 10 and 13 DPF with MDHT at a concentration of 500 mg/l caused masculinization. Conversely, MT at similar levels did not significantly alter the sex ratio. Lack of an effect in the MT treatment (500 mg/l) may be due to conversion of MT to a less active form or simply a higher rate of clearance from the body than MDHT. Another possible explanation for the differing effects of the two steroids is that MDHT is a more potent masculinizing agent than MT. Piferrer et al. (1993) found that MDHT was twice as potent as MT in masculinizing female chinook salmon. Furthermore,

Table 1. Mortality data for experiment 1 (EX 1) and 2 (EX2). Group abbreviations and sample sizes are the same as given in Figure 1.

Group	Mortality (%)	
	EX 1	*EX 2*
MT-100	58	26
MT-500	46	64
MDHT-100	53	33
MDHT-500	63	33
ETH	59	22
CTL	81	35
FED	62	--

MDHT can bind to androgen receptors in Nile tilapia gonads (Gale, 1996) and coho salmon (*O. kisutch*) ovaries (Fitzpatrick et al., 1995). These binding sites are specific for sex-inverting androgens, and are found in the gonadal cytosol.

Immersion treatment did not significantly affect mortality. Although mortality was not significantly different between treatments, fry in experiment 1 did suffer a higher mortality than did individuals in experiment 2. This discrepancy is likely due to improvements in culture conditions. Fish in experiment 1 were held at a density of 33 fish/l for 20 days (30 DPF) and then placed in grow-out tanks at a density of 5 fish/l. Fish in experiment 2 were held at the 33 fish/l density for only three days (13 DPF) and then transferred into grow-out tanks at a density of 5 fish/l.

Administration of steroid by incorporation in feed has a long history of use (see reviews by Schreck, 1974, and Hunter and Donaldson, 1983). Steroid is dissolved in a carrier (e.g., ethanol or acetone), uniformly mixed with feed, and allowed to dry before use. Fry are fed for several weeks, beginning between 10 and 14 DPF (Shelton et al., 1981; Nakamura and Iwahashi, 1982). Although this technique usually results in successful sex inversion, certain inefficiencies are cause for concern. MacIntosh and Little (1995) point out that any condition that adversely affects food consumption may decrease treatment efficacy. The dose received by an individual fish is variable—being dependent on body size, social status, and consumption of naturally-occurring food. This may result in an uneven distribution of steroid. The culturist must then accept partial or incomplete sex inversion or increase the treatment dose beyond the optimal requirement to achieve 100% sex inversion under laboratory conditions. Furthermore, the long period of treatment employed by typical feeding methods results in human handling of anabolic steroid three to five times daily for up to 35 days. This degree of handling presents an added risk to

Table 2. Mean weight and standard length (±SE) from sampled fish in experiment 2. Group designations and sample sizes are the same as given in Figure 1.

Group	Weight (g)	Length (mm)
MT-100	2.77 ± 0.21	41.7 ± 1.2
MT-500	3.45 ± 0.21	44.4 ± 1.0
MDHT-100	2.95 ± 0.30	41.7 ± 1.4
MDHT-500	3.29 ± 0.22	43.7 ± 1.1
ETH	2.97 ± 0.26	42.5 ± 1.3
CTL	3.17 ± 0.23	42.2 ± 1.0

the aquaculture worker, given the tumorigenic and teratogenic effects of anabolic androgenic steroids (Lewis and Sweet, 1993). This risk is easily mitigated by the establishment of proper handling procedures; however, these precautions are often improperly implemented. For instance, in developing countries, where much of the worldwide tilapia production occurs, disposable rubber gloves for the handling of treated feed may be either unavailable or too expensive to be practical. Furthermore, in developing countries workers generally have little or no protective clothing (e.g., rubber waders) for working in ponds containing dissolved steroid. Therefore, techniques that reduce worker exposure to anabolic steroid but are as (or more) effective as feeding treatments need to be established.

The technique described in our study consisting of immersion in MDHT decreases the treatment period, thereby reducing worker exposure while still achieving nearly complete masculinization. This technique is a promising alternative to the use of steroid-treated feed, but further evaluation is needed before application in large-scale aquaculture operations.

Acknowledgments

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Literature Cited

Fitzpatrick, M.S., W.L. Gale, and C.B. Schreck, 1995. Binding characteristics of an androgen receptor in the ovaries of coho salmon, *Oncorhynchus kisutch*. Gen. Comp. Endocrinol., 95:399-408.

Gale, W.L., 1996. Sexual differentiation and steroid-induced sex inversion in Nile tilapia *(Oreochromis niloticus)*: 1. characterization of a gonadal androgen receptor. 2. Masculinization by immersion in methyldihydrotestosterone. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA, 57 pp.

Hunter, G.A. and E.M. Donaldson, 1983. Hormonal sex control and its application to fish culture. In: W.S. Hoar, D.J. Randall, and E.M. Donaldson (Editors), Fish Physiology, Reproduction, Behaviour, and Fertility Control, Vol. IX-B. Academic Press, New York, pp. 223-303.

Lewis, R.J. and D.V. Sweet, 1993. Registry of toxic effects of chemical substances. U.S. Dept. Health and Human Services, Public Services, Centers for Disease Control, National Institutes Occupational Safety and Health, Cincinnati, Ohio, USA, 70 pp.

MacIntosh, D.J. and D.C. Little, 1995. Nile tilapia *(Oreochromis niloticus)*. In: N.R. Bromage and R.J. Roberts (Editors), Broodstock Management and Egg and Larval Quality, Chapter 12. Blackwell Scientific Ltd., Cambridge, Massachusetts, USA, pp. 277-320.

Mires, D., 1995. The tilapias. In: C.E. Nash and A.J. Novotony (Editors), Production of Aquatic Animals, Chapter 7. Elsevier, New York, pp. 133-152.

Nakamura, M. and M. Iwahashi, 1982. Studies on the practical masculinization of *Tilapia nilotica* by oral administration of androgen. Bull. Jpn. Soc. Sci. Fish., 48:763-769.

Pandian, K. and T.J. Varadaraj, 1987. Masculinization of *Oreochromis mossambicus* by administration of 17α-methyl-5-androsten-3β-17β-diol through rearing water. Current Science, 56:412-413.

Piferrer, F. and E.M. Donaldson, 1991. Dosage-dependent differences in the effect of aromatizable and nonaromatizable androgens on the resulting phenotype of coho salmon *(Oncorhynchus kisutch)*. Fish Physiol. Biochem., 9:145-150.

Piferrer, F., I.J. Baker, and E.M. Donaldson, 1993. Effects of natural, synthetic, aromatizable, and nonaromatizable androgens in inducing male sex differentiation in genotypic female chinook salmon *(Oncorhynchus tshawytscha)*. Gen. Comp. Endocrinol., 91:59-65.

Schreck C.B., 1974. Hormonal treatment and sex manipulation in fishes. In: C.B. Schreck (Editor), Control of Sex in Fishes. Sea Grant Extension Division, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, pp. 84-106.

Shelton, W.L., D. Rodriguez-Guerrero, and J. Lopez-Macias, 1981. Factors affecting androgen sex reversal of *Tilapia aurea*. Aquaculture, 25:59-65.

Torrans, L., F. Meriwether, F. Lowell, B. Wyatt, and P.D. Gwinup, 1988. Sex-reversal of *Oreochromis aureus* by immersion in mibolerone, a synthetic steroid. J. World Aqua. Soc., 19:97-102.

Wittman, W., 1962. Aceto-iron hematoxylin for staining chromosomes in squashes of plant material. Stain Technology, 37:27-30.

Zar, J.H., 1984. Biostatistical Analysis, Second Edition. Prentice and Hall, Inc., Englewood Cliffs, New Jersey, USA, 718 pp.

Experimental Evaluation of Lime Requirement Estimators for Global Sites

Interim Work Plan, Africa Study 3

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Introduction

Aquaculture ponds with acid-bottom muds and soft waters are commonly treated with lime to raise soil pH and base saturation levels and to increase the alkalinity of the pond water to an acceptable level. Pond mud pH readings of less than about 6.0 or pond water alkalinities of 20 mg $CaCO_3$/l or less are indications that a given pond needs to be limed (Boyd, 1979). Aquaculturists have used a number of methods (both agricultural and aquacultural) to estimate the amount of lime that should be added to ponds. Agricultural methods generally estimate the lime requirement (LR) for raising soil pH to a particular level; however, aquacultural methods go a step further and estimate the LR for raising pond water alkalinity to a desired level.

Study B of Work Plan Seven (revised) was designed to determine whether different LR estimation procedures produced similar results and to evaluate the suitability of different estimators for different types of soils by testing them in laboratory microcosms. Those experiments, reported in the Thirteenth Annual Technical Report (Bowman and Seim, 1995a; 1995b) demonstrated that different methods for the estimation of LRs produced varied results and that the use of some methods did not always achieve the desired results in terms of alkalinity in the water column. This study, an extension of Study B of Workplan Seven, was designed to 1) investigate the use of artificial enclosures (“isolation columns”) as in-pond test units for liming studies, and 2) compare the results obtained in such enclosures with results obtained in laboratory microcosms.

Materials and Methods

A pond with acid soil and low-alkalinity water at Soap Creek (Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, USA) was selected for the installation of isolation columns (ICs). Soil samples were collected from the top 10 cm of soil in the 1-m deep area of the pond using a 5-cm PVC core sampler. The samples were air-dried and crushed to pass a 2-mm sieve, and subsamples were submitted to the Soil Physics Laboratory and the Central Analytical Laboratory (Department of Crop and Soil Science) at OSU for characterization. Analyses included determination of the sand, silt, and clay contents of the mineral fraction, pH, acidity, exchangeable

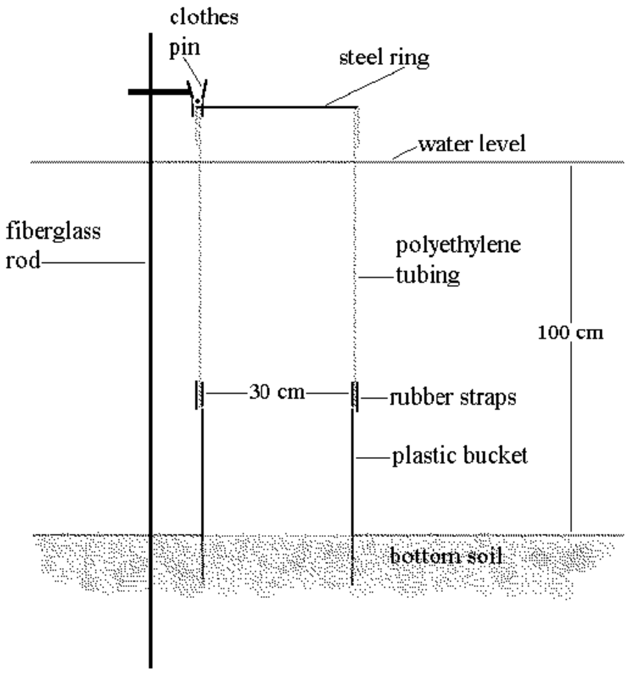

Figure 1. Design (not drawn to scale) of the artificial enclosures (isolation columns) used in the study. All materials used were locally available with the exception of the "layflat", polyethylene tubing ordered from a plastics distributor.

bases (Ca, Mg, Na, K), SMP lime requirement, percent organic carbon, and total nitrogen content. Percent base saturation, percent organic matter (OM), and estimated cation exchange capacity (CEC) of the clay fraction were calculated using appropriate data from these analyses. Another subsample was used to determine pond lime requirement by the method of Pillai and Boyd (1985).

Isolation columns were constructed using 5-gallon plastic buckets (with the bottoms cut out), 29-cm diameter "layflat" polyethylene tubing, rigid 30-cm steel rings, plastic clothespins, and 6-ft fiberglass plant stakes (Figure 1). Six of these columns were pressed firmly into the pond bottom (minimum depth of 10 cm into the soil) in an already-filled pond at Soap Creek. The columns were placed along a pond-bottom contour where the water depth was approximately 1 m. Two treatments were applied to the columns in triplicate: three columns were limed according to the Pillai and Boyd (1985) estimate, and three columns were left unlimed.

Laboratory microcosms (MCs) were set up in a constant temperature room at the Oak Creek Laboratory of Biology, Oregon State University, Corvallis, Oregon. Glass beakers with a capacity of 800 ml were filled with 750 ml of soft dilution water (alkalinity of approximately 18 mg $CaCO_3$/l, to approximate the alkalinity of the pond at Soap Creek). The appropriate amount of agricultural limestone was thoroughly mixed with 25 g of the soil from the Soap Creek pond and then added to the dilution water. The soil-lime-water mixture was stirred vigorously with a glass rod for ten seconds to begin the experiment. An unlimed treatment and a control (no soil or limestone) were also prepared. Each treatment was applied in triplicate. Water temperatures in the MCs were maintained between 23 and 26°C for the duration of the experiment. Samples of approximately 12.5 ml were removed after 1, 3, 7, 14, 21, and 28 days (on the same schedule as the samples from the isolation columns) for determination of total alkalinity. Alkalinity was determined according to the methods described in *Standard Methods* (APHA, 1989).

Water column samples were collected from the ICs and MCs after 1, 3, 7, 14, 21, and 28 days for total alkalinity determination. Samples were taken from the ICs at approximately 1100 hours and from the MCs at approximately 1400 hours on each sampling day. The experiment was initiated on July 12, 1995, and completed after 28 days, on August 9, 1995. The initiation, completion, and sampling dates for the isolation column component and the laboratory component of the experiment were the same.

Results and Discussion

The physical and chemical characteristics of the Soap Creek pond bottom soil (also used in the MCs) are shown in Table 1. The textural class of the soil was clay (48.7%), and it had a CEC of 51.45 cmol/kg. The estimated CEC of the clay fraction was approximately 106 cmol/kg, which suggests that it is comprised mainly of 2:1-type clay minerals. The soil survey for the Benton County area (USDA, 1975) also places the soils at Soap Creek in the fine (35-59% clay), montmorillonitic (a 2:1-type clay mineral) class. These characteristics put the soil in the 2:1 Clayey class used in the POND© Version 2 (Bolte at al., 1994) soil classification system. The soil had a pH of 6.82, and its percent base saturation was approximately 90. The LR estimated for this soil by the SMP method (Shoemaker et al., 1961) was 1519 kg/ha, whereas the LR estimated by the Pillai and Boyd (1985) method was considerably higher at 5086 kg/ha.

Total alkalinity trends (mean treatment values) for samples taken from the Soap Creek pond (ICs and open pond) and the laboratory microcosms (MCs) are shown in Figure 2. The alkalinity trend for limed ICs shows an increase from the initial value of 18.31 to almost 30 mg/l (as $CaCO_3$) during the first day and a subsequent gradual increase over the 28 days of the experiment, with a final alkalinity of 52.25 mg/l. Data from one replicate of the limed IC treatment was excluded from analysis because it deviated considerably from the mean for the treatment, suggesting some large source of error. Liming at the rate determined by the Pillai and Boyd (1985) method was successful in raising and maintaining total alkalinity to the desired level in the ICs. Visual inspection suggests that the alkalinity trend for unlimed ICs was similar to that of the open pond. In contrast with the trend for limed ICs, these alkalinities rose only slightly from the initial value of 18.31 mg/l, and neither ever exceeded 26 mg/l, indicating that the effect of the isolation column itself on alkalinity was minimal over the period of this experiment. This suggests that the use of isolation columns of this size and design may be reasonable for this type of testing; however, a Newman-Keuls multiple range test showed them to be significantly different at the 95% confidence level (Table 2).

In the laboratory, the alkalinity of limed MCs rose rapidly from an initial level of 18.09 to 29.95 mg/l during the first day, and it continued to rise until it peaked at 62.13 mg/l on day 14. Alkalinity then gradually declined to 52.02 mg/l on day 28. Alkalinity in unlimed MCs rose from an initial level

Table 1. Soil characterization data for Soap Creek Pond 7.

Variable	Value
% Sand	11.5
% Silt	39.8
% Clay	48.7
Textural Class	clay
pH	6.82
Acidity (meq/100 g)	10.45
Ca (meq/100 g)	29.45
Mg (meq/100 g)	16.40
Na (meq/100 g)	0.20
K (ppm)	90.00
K (meq/100 g)*	0.23
Sum of Bases (meq/100 g)	46.28
CEC (meq/100 g) (by analysis)	51.45
CEC (meq/100 g) (by sum of cations)	56.73
Estimated CEC of Clay (meq/100 g)	105.65
Probable Mineralogy Class	2:1 clayey
Base Saturation (%) (by analysis)	90.0
Base Saturation (%) (by sum of cations)	81.6
SMP Lime Requirement (kg/ha)	1519
Pillay & Boyd Lime Requirement (kg/ha)	5086
% Carbon	0.55
% Organic Matter**	0.93
Total Nitrogen	0.04

* Calculated as ppm K/391.
** Calculated as 1.7 x %C.

Table 2. Newman-Keuls multiple range test results for alkalinities on day 28 of the isolation column experiment.

Treatment	Count	Mean Alkalinity (mg/l)	Homogeneous Groups
Unlimed Microcosm	3	11.88	*
Laboratory Control	3	19.32	*
Unlimed Isolation Column	3	23.45	*
Open Pond	3	25.70	*
Limed Microcosm	3	52.02	*
Limed Isolation Column	2	52.25	*

* Denotes a statistically significant difference.

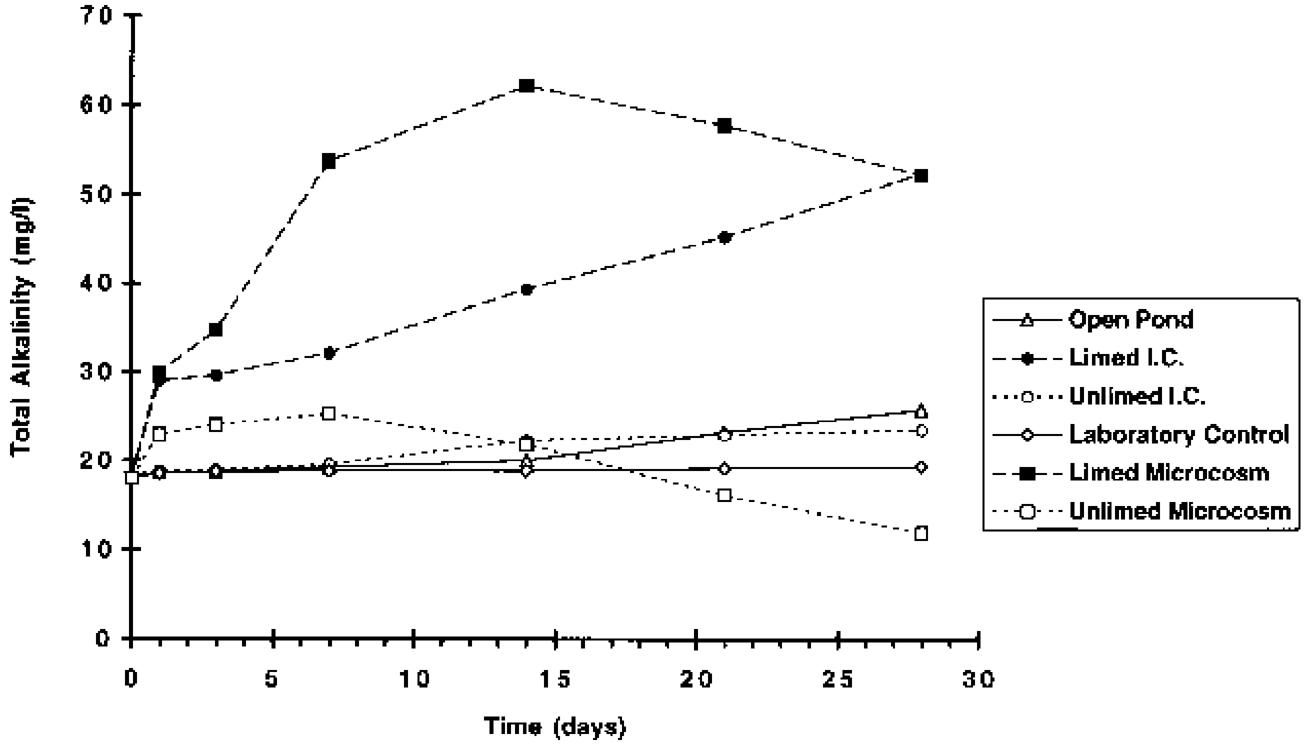

Figure 2. Trends in total alkalinity for limed and unlimed in-pond enclosures (isolation columns), open pond water, and limed and unlimed laboratory microcosms containing soil from the same pond. Limed and unlimed isolation columns and microcosms treated identically responded differently. The alkalinity trends in unlimed isolation columns were similar to the alkalinity trend of the open pond.

of 18.09 to 25.25 mg/l on day 7 but then dropped steadily over the remainder of the experiment to a level of 11.88 mg/l by the end of the experiment. This trend illustrates the depletion of alkalinity by acid soils discussed by Boyd (1979). Alkalinity in laboratory controls remained virtually unchanged throughout the experiment.

A comparison of results from the laboratory MCs with those of the ICs and the open pond reveals different responses to identical treatments in the two systems. The alkalinity increase in limed MCs during the first day matched almost exactly that of the limed ICs at Soap Creek (18.09 to 29.95 mg/l and 18.31 to 28.83 mg/l, respectively), but the two systems behaved very differently over most of the remainder of the experiment, diverging widely by day 14 before beginning to converge near the end of the experiment. By day 28, however, mean alkalinities in these two systems were not greatly different (Figure 2), with alkalinities in the ICs averaging 52.25 mg/l and alkalinities in the MCs averaging 52.02 mg/l. Unlimed MCs and ICs also behaved differently; IC alkalinities remained nearly constant through the course of the experiment while MC alkalinities rose slightly before decreasing to below 12 mg/l by day 28. Multiple range analysis of day-28 alkalinities (Newman-Keuls, 95% confidence level) showed significant differences among all treatments except the limed ICs and the limed MCs, which formed a homogeneous group (Table 2). The noticeable differences among alkalinity trends in laboratory MCs and pond ICs suggests that one or both of these systems may not adequately simulate the effects of liming in real ponds although the similarity of the alkalinity trends in unlimed ICs and the open pond suggests that ICs of this design and size may have some potential as test units in aquaculture ponds.

Some mention should be made of the practical aspects of installing and using the ICs. Installation in already-filled ponds was found to be somewhat more difficult than originally anticipated because the normal algal bloom in the pond, together with mud turbidity caused by working in the area, made it impossible to see the pond bottom or even the top of the bucket portion of the ICs during installation. Another problem was that both the polyethylene tubing and the top of the plastic bucket itself were very slippery, making it difficult to apply firm, steady pressure to the top of the bucket to press it down into the pond bottom. Finally, care had to be taken while inserting the fiberglass support rods into the pond bottom, as a slight misjudgment during this operation could result in the polyethylene tubing being punctured.

Some problems were also encountered after installation. The first was that it was necessary to adjust the level of the top of the IC to compensate for decreases or increases in water level in the pond, and this was difficult to do with the design tested. A second problem was related to an as-yet not understood phenomenon that occurred in the limed ICs. Towards the middle of the experiment, from about day 11 on, losses of water volume (evidenced by a partial inwards collapsing of the polyethylene column) were observed in these ICs but not in the unlimed ICs. One hypothesis was that a soil-limestone interaction occurred in the bottom soil, thereby sealing it and preventing evaporation replacement water from entering the IC from the bottom. Another hypothesis was that $CaCO_3$ interacts with the polyethylene itself, sealing it against water movement. It might be useful to carry out further tests of isolation columns to determine if simple designs such as the one tested in this study can be improved for easier installation and maintenance, and to verify if in-column reactions are truly representative of the reactions that occur when the same treatments are applied to open ponds.

Anticipated Benefits

The in-pond enclosures of the type tested appear to be suitable for conducting lime application experiments, although design improvements and further testing would be beneficial. If enclosures that are consistently reliable can be developed, they might be used for testing a number of different kinds of pond treatments within single ponds. This may result in reduced variability among experimental units and in considerable reductions in the amounts of pond space, time, and other costs required to conduct pond-based research.

Literature Cited

American Public Health Association (APHA), 1989. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Washington, D.C.

Bolte, J., S. Nath, D. Ernst, and M. Tice, 1994. POND© Version 2 (software and manual). Oregon State University Biosystems Analysis Group. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, 36 pp.

Boyd, C.E., 1979. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station. Auburn, Alabama, USA.

Bowman, J. and W. Seim, 1995a. Experimental evaluation of lime requirement estimators for global sites. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 27-32.

Bowman, J. and W. Seim, 1995b. Experimental evaluation of lime requirement estimators for global sites-Isolation column experiments. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp.33-35.

Pillai V.K. and C.E. Boyd, 1985. A simple method for calculating liming rates for fish ponds. Aquaculture, 46:157-162.

Shoemaker, H.E., E.O. McLean, and P.F. Pratt, 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminum. Soil Science Society of America Proceedings, 25:274-277.

USDA (United State Department of Agriculture, Soil Conservation Service, in cooperation with the Oregon Agricultural Experiment Station), 1975. Soil survey of Benton County area, Oregon. Soil Conservation Service, United States Department of Agriculture, Washington, D.C.

Characterization of Soils from Potential PD/A CRSP Sites in East Africa

Interim Work Plan, Africa Study 4

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Introduction

The termination of research activities at the Rwasave Fish Culture Station in Rwanda, due to civil war in 1994, led PD/A CRSP/Africa researchers to revise many of the activities of Work Plan 7 and to begin the search for a new PD/A CRSP research site in Africa. Two aquaculture sites in Kenya were evaluated as future CRSP research sites. Pond soil samples were collected and characterized. Study 4 of the Interim Work Plan complemented that activity by providing for the collection and analysis of soil samples from additional sites. The soil characterization data obtained were intended to supplement other information about each site to be used in evaluating and selecting the new prime site for Africa.

Materials and Methods

Soil samples were collected from pond bottoms at five potential research sites in East Africa during country and site evaluation visits conducted on three trips made in 1994 and 1995. In Kenya, samples were collected at Sagana Fish Culture Farm (SFCF), Sagana, at Kibos Fry Production Centre, near Kisumu; and at the Baobab Farm, near Mombasa. Samples were also collected from ponds at the Lake Chivero Fisheries Station, near Harare, Zimbabwe, and at the Bunda College aquaculture facility, near Lilongwe, Malawi.

Sampling methods and sample sizes varied according to constraints faced by the researchers participating on the site evaluation trips. At SFCF, a composite sample was collected from each of three ponds (one each from the B, C, and D pond series, near the center of the farm) as well as from a soybean field on the west side of the farm. At Mombasa, samples were collected at the roadside near the entrance to the facility. Time constraints allowed for the collection of only one composite sample each at the Lake Chivero (Zimbabwe), Kibos (Kenya), and Bunda College (Malawi) sites. Most samples were collected using PVC core samplers inserted into pond bottoms to a depth of 15 cm. At Kibos and Bunda College, however, 15-cm-deep samples were collected using a shovel. There was an abrupt margin between horizons at a depth of 7 cm in the sample collected at Lake Chivero, so this sample was divided into two subsamples for analysis. All samples were air-dried as much as possible in-country before being returned to Oregon State University (OSU).

At OSU, samples were further prepared for analysis by completing air drying as necessary and crushing to pass a No. 10 (2 mm) sieve at the Oak Creek Laboratory, Department of Fisheries and Wildlife. Subsamples were then analyzed for sand, silt, and clay contents of the mineral fraction, organic carbon, pH, acidity, exchangeable bases (Ca, Mg, Na, K), SMP lime requirement, and total nitrogen content. Analyses were completed at the Oak Creek Laboratory and at the Central Analytical Laboratory (Crop and Soil Science) on the main campus. Base saturation, CEC of the clay fraction, and organic matter (OM) contents were estimated from the analytical data obtained.

Results and Discussion

The physical and chemical composition of each soil sample is shown in Tables 1-3. As might be expected, most samples taken from sites with earthen ponds had clay contents of 25% or more (Table 1). A notable exception was the lower (7- to 15-cm) horizon of the sample from Pond 3 at the Lake Chivero (Zimbabwe) site, which had a clay content of only 4.4%. The upper (0- to 7-cm) horizon in this pond had a clay content of 29.1%, which suggests that a blanket of clay may have

Table 1. Composition of soils sampled at African sites in 1994 and 1995.

Source	Sand*	Silt*	Clay*	Textural	Particle-size	O.M.
	(%)	(%)	(%)	Class	Class	(%)**
Sagana (Pond D2)	5.8	12.5	81.7	clay	2:1 Clayey	3.88
Sagana (Soya field)	11.6	17.3	71.1	clay	Mixed Clayey	3.89
Kibos	32.4	29.3	38.2	cl. loam	2:1 Clayey	2.62
Chivero (0 - 7 cm)	51.0	19.9	29.1	s. cl. loam	Fine-loamy	3.90
Chivero (7 - 15 cm)	82.1	13.5	4.4	l. sand	Coarse-loamy	0.25
Bunda College	16.6	15.1	68.4	clay	2:1 Clayey	6.31
Sagana (Pond B2)	30.7	10.2	59.1	clay	Clayey	---
Sagana (Pond C6)	10.9	12.1	77.0	clay	Clayey	---
Mombasa	28.9	21.5	49.7	clay	Clayey	---

* Percentage of the mineral fraction.
** Organic matter, calculated as 1.7 x % organic carbon.

been applied to the pond during or after construction to prevent excessive seepage. It should also be noted that the original Mombasa soil sample contained a high proportion of coral fragments ranging in size from 4 mm to 10 cm in diameter or length, and that the clay content shown in Table 1 (49.7%), is for the fine earth (< 2 mm) fraction of the sample. The actual overall clay percentage of the soil at the Mombasa site was lower, and soils there were clearly too porous to retain water; this was also evidenced by the fact that the fish culture operation there was conducted entirely in concrete tanks. With the exception of these two soil samples, the physical characteristics of the soil at all sites evaluated would have been satisfactory for good water retention. Clay contents in some of the other samples were *very* high; for example, Pond D2 at Sagana was 81.7%.

The soil sample obtained from Kibos, Kenya, was described by station personnel as a “black cotton” soil. That sample, as well as the one from Bunda College, Malawi, did indeed have the appearance and some of the characteristics of this soil type: very dark brown to black colors, high contents of very sticky clay, relatively high pH values and base saturation percentages, and, in the case of the Bunda

Table 3. Exchangeable base contents of soils sampled at African sites in 1994 and 1995.

Source	Ca (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	K (meq/100 g)	Sum of Bases (meq/100 g)
Sagana (Pond D2)	20.03	15.87	0.18	0.00	36.08
Sagana (Soya Field)	9.60	8.70	0.02	0.00	18.32
Kibos	20.40	4.75	0.90	0.35	26.40
Chivero (0 - 7 cm)	4.40	1.70	0.51	0.28	6.89
Chivero (7 - 15 cm)	0.65	0.26	0.12	0.05	1.07
Bunda College	30.05	14.65	0.90	0.42	46.02
Sagana (Pond B2)	*	*	*	*	*
Sagana (Pond C6)	*	*	*	*	*
Mombasa	*	*	*	*	*

* Percentage of the mineral fraction.
** Organic matter, calculated as 1.7 x % organic carbon.

Table 2. Chemical characteristics of soils sampled at African sites in 1994 and 1995.

Source	pH	Acidity (meq/100 g)	Sum of Bases (meq/100 g)	Soil CEC (meq/100 g)	Clay CEC** (meq/100 g)	Base Sat. (%)	Organic Carbon (%)	Organic Matter (%)***	SMP Lime Req. (kg/ha)	Total Nitrogen (TN)
Sagana (Pond D2)	5.08	20.83	36.08	47.23	57.81	76.39	2.28	3.88	10898	0.18
Sagana (Soya field)	5.44	15.53	18.32	26.63	37.45	68.79	2.29	3.89	8430	0.19
Kibos	6.55	6.90	26.40	27.70	72.51	95.30	1.54	2.62	1519	0.11
Chivero (0-7 cm)	5.20	7.25	6.89	9.40	n/a	73.34	2.30	3.90	4418	0.21
Chivero (7-15 cm)	5.55	1.50	1.07	1.25	n/a	86.00	0.15	0.25	0	0.00
Bunda College	6.85	11.80	46.02	46.20	67.54	99.61	3.71	6.31	1519	0.23
Sagana (Pond B2)	7.62	*	*	*	*	*	*	*	*	*
Sagana (Pond C6)	7.22	*	*	*	*	*	*	*	*	*
Mombasa	8.01	*	*	*	*	*	*	*	*	*

* Full analyses not carried out on alkaline samples.
** Calculated as Soil CEC/percent Clay*100.
*** Calculated as 1.7 x percent organic carbon.

College sample, a relatively high cation exchange capacity (CEC). The reactions of these soils were nearly neutral, with pH values of 6.55 and 6.85 and base saturation percentages of 95.3 and 99.6, respectively. Their CEC values were 27.7 and 46.2 cmol/kg soil, respectively. SMP lime requirements for these nearly neutral soils were relatively low (1519 kg/ha for both). The estimated CECs of the clay fractions of these soils (72.5 and 67.5 cmol/kg, respectively) suggest that in the absence of high levels of OM, a relatively high content of 2:1-type clay minerals such as smectite exists. This would be expected for "black cotton" soils. Such soils have several potential advantages in aquaculture, including low permeability, relatively high availability of nutrients, relatively low amounts of acidity, and high base saturation percentages, which result in minimal lime requirements.

Samples from the other sites were all quite acidic, with pH values ranging from 5.08 to 5.55. Base saturation percentages, however, were all greater than 68%. CECs from the Lake Chivero samples were quite low, at 1.25 and 9.40 cmol/kg (lower and upper horizons, respectively), but those from the Sagana soya field and Kibos were 26.63 and 27.70 cmol/kg, respectively. These values reflect the clay contents of the soils, and—to some extent—the type of clay present. The pH, CEC, and base saturation percentage relationships of these soils were reflected in their SMP lime requirements, which ranged from a low of 0 kg/ha (lower horizon, Lake Chivero) to a high of 10,898 kg/ha (Pond D2 at Sagana) (Table 2). With the exception of the Bunda College sample, the OM content of all samples was within the normal range expected in aquaculture ponds (Tables 1 and 2). Even the OM content of the Bunda sample (6.31%) was only slightly higher than the usual range of 0-5% observed in ponds (Boyd, 1979). Table 3 shows the proportions of the exchangeable bases (Ca, Mg, Na, and K) of the soils collected.

Anticipated Benefits

The characteristics of soils at different potential new research sites contributed to our overall understanding of the nature of the sites and to the final selection of the Sagana site. Ultimately, however, soil character played a minor role in the selection of a site for continued PD/A CRSP research in Africa. Only the Mombasa site was clearly unacceptable in terms of soil quality. Other site selection criteria, such as the existing physical infrastructure (ponds, lab facilities, communications, etc.), country political stability, potential USAID support, and factors such as the species available for use in the research program clearly outweighed soil character in importance as factors to be considered.

Literature Cited

Boyd, C.E., 1979. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station. Auburn, Alabama, USA.

Effect of Feed Storage Time and Storage Temperature on Growth Rate of Tilapia Fry and Efficacy of Sex Reversal

Interim Work Plan, Africa Study 8

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Introduction

Early expansion of tilapia culture was limited because tilapia sexually mature at an early age, which can result in overcrowding in the culture system and in stunted growth. (Hickling, 1963; Hepher and Pruginin, 1981). Methods for culturing exclusively male tilapia, including sex reversal, have been developed to address these problems.

All-male tilapia are produced through sex reversal, that is, by treating fry with a male hormone, such as methyltestosterone or ethynyltestosterone before the primal gonadal cells of females have differentiated into ovarian tissue. Factors that affect sex reversal include: type of hormone, duration of treatment, water quality and temperature, fry stocking density, age and length of fry, quality of feed, and feeding rate. Varadaraj et al. (1994) identified additional factors that should be taken into account: genetics, purity and dosage of hormone, solubility of hormone in solvent, and salinity of the rearing water. The feed manufacturing process can reduce the potency of a steroid. Pure methyltestosterone, a stable, light-sensitive hormone with a melting point between 162 and 167°C, should be stored at room temperature in a sealed, light-proof, amber bottle (Budavari et al., 1989; Sigma Chemical Company, 1994). Varadaraj et al. (1994) also concluded that sub-optimal storage of the hormone and hormone-treated feed can greatly affect their efficacy. Feed should be stored in closed containers of multi-wall construction with plastic liners and kept in a cool, dry place at ambient temperature. Older food should be used first, thus feed containers should be carefully labeled and dated.

Feed stored for longer than 90 days at ambient temperature is subject to the breakdown of oils, vitamin C, vitamin E, and other vitamins, along with peroxidation of the lipid component (National Research Council, 1981). When fish are given feed deficient in vitamin C, the first vitamin to break down, skin lesions and the disease head and lateral line erosion (HLLE) may result (Jauncey and Ross, 1982). In addition, a mold containing an aflatoxin, which is toxic to fish, may grow in humid environments if storage temperatures rise. Food that has been subject to degradation may inhibit growth and cause vitamin deficiencies, making fish more susceptible to disease (Jauncey and Ross, 1982). Poor storage may also result in off-flavors and odors in the feed, making it less palatable to fish.

Feed availability is often a consideration in sex reversal. Because hormone-treated feed is generally refrigerated, extensive use of the sex-reversal process has been limited to farms with refrigeration facilities. The research described in this report addresses the relative shelf life of hormone-treated feed used for sex reversal at ambient tropical temperature.

Materials and Methods

Research was conducted at the El Carao National Fish Culture Research Center, General Directorate of Fisheries and Aquaculture, Ministry of Natural Resources, Comayagua, Honduras from January 6 to September 6, 1995.

Feed

The basal feed used was Zeigler Mash (55% protein; 13% carbohydrate; 15% fat; 8-10% moisture content; 8-9% ash; < 1% fiber), stored in a -2°C freezer.

Hormone Feed Preparation

A hormone feed containing 60 mg/kg of 17α-methyltestosterone (MT) was prepared according to the Zeigler Inc. method (personal communication, 1995). A stock solution, stored in a refrigerator at 4°C, was prepared by dissolving 3 g of the MT in 1,000 ml of 95% ethyl alcohol. Sixty ml of the stock solution were then mixed with 630 ml of 90% ethyl alcohol and sprayed on 3 kg of feed in a covered mixer and thoroughly mixed for 20 minutes. Twenty 3-kg batches were pooled together and a 5 cm-layer of feed was then spread on tables in the laboratory at 26°C for 12 hours to allow the solvent to evaporate. The next day the feed was hermetically sealed in plastic zip-lock bags and placed in a freezer at -2°C. The control feed was sprayed with the same alcohol solution as the hormone-prepared diets and remained in the freezer until the day of use. Feeds were taken out of the freezer at their designated times and placed in the refrigerator at 4°C or placed in a sealed cardboard box on a shelf in the laboratory at tropical ambient temperature (28° ± 1.5°C).

Six hormone treated feeds were stored in the following manner:

- 26 days at ambient temperature,
- seven days at ambient temperature,
- zero days at ambient temperature,
- 60 days in the refrigerator and 26 days at ambient temperature,
- 60 days in the refrigerator and seven days at ambient temperature,
- 60 days in the refrigerator and zero days at ambient temperature.

An additional set of fish were fed a non-hormone treated feed that was stored in a dark freezer for 87 days prior to use.

Fry stocking

Oreochromis niloticus fry (Ivory Coast strain; Abdelhamid, 1988), with an initial mean length of 10.4 mm total length, were stocked in hapas. The hapas were suspended from a wooden pier in a 0.1-ha pond with a maximum depth of 1.2 m and a minimum depth of 0.7 m. The hapas measured 1.0 x 1.0 x 0.7 m (length x width x height) and contained 0.5 m^3 of water.

Fry less than 14 mm and 14 days old were harvested from a 0.05-ha pond, counted by visual comparison, and stocked into hapas at 4,000/m^3. Visual comparison was accomplished by counting 500 fry into 5 cm of water in a 5-gallon white bucket. Fry were then added to a second bucket until the numbers of fry in each bucket appeared to be the same.

Daily ration

Daily feed quantities were weighed the morning of feeding and sealed in clear plastic jars. The jars were placed outdoors in white plastic containers. Fry were fed four times daily for 28 days. The feeding rate was adjusted weekly by measuring 25 fish per hapa to the nearest millimeter and estimating biomass per hapa using the length-weight formula described by Shelton et al. (1978). The weekly feeding rates were 15, 12, 8 and 4% body weight per day during weeks 1, 2, 3, and 4, respectively.

Harvesting

After 28 days of hormone treatment, fry were harvested and weighed to the nearest 0.1 g. One hundred individuals were measured to the nearest millimeter to determine the length-frequency distribution. Five hundred fry were returned to the hapas and grown to a size of at least 4 cm.

After they reached 4 cm, the fingerlings were harvested and stored in 10% formalin. A sample of 100 fish, representing the length-frequency of the population, was sexed following the procedure described by Guerrero and Shelton (1974). Gonads were identified as male, female, or intersex. Intersex gonads were defined as those having ovarian and testicular tissue and were described by the percentage of ovarian tissue present relative to the whole gonad.

Feed Analyses

Feed samples were analyzed for MT degradation and lipid oxidation. The degree of lipid oxidation was found by determining the peroxide value—the amount of iodine liberated from a saturated potassium-iodide solution at room temperature. The lipid is extracted from the feed using the procedures described by Bligh and Dyer (1959) or Folch et al. (1957). The peroxide value is expressed in milliequivalent of peroxide per kilogram (meg/kg) fat (AOAC, 1990). This analysis was done on two samples—the first sample remained frozen from January 30, 1995, to November 22, 1995, and the second sample after stratification and storage for

Table 1. Sex of *Oreochromis niloticus* fry fed for 28-days a diet containing 60 mg MT/kg. The feed was stored for different durations of refrigeration and at ambient air temperature. Data are means of 4 replicates (100 fish/replicate). No significant differences (P > 0.05) were observed among treatments for any parameter.

Duration of Storage time (days)		% Males	% Females	% Intersex	Total No. of Fish Sexed
Refrigerator at 4°C	*Ambient Temperature*				
Control	Control	50	50	0	400
0	0	100	0	0	400
0	7	100	0	0	400
0	28	100	0	0	400
60	0	100	0	0	400
60	7	99	0	1	400
60	28	100	0	1	400

two months in a refrigerator, was kept for 26 days at tropical ambient temperature and returned to the freezer for 180 days (May 25 to November 22, 1995). The analysis was performed by Woodson-Tenent Laboratories, Inc., Memphis, Tennessee.

Methyltestosterone analyses were conducted by CanTest Ltd., Vancouver, B.C., using high performance liquid chromatography (HPLC) with UV detection (Syndel Laboratories Ltd., 1993). Three samples were analyzed:

1) a control feed sample that contained no hormone but had been stored in a dark freezer from (January 30 to December 1, 1995);
2) a feed sample containing 60 mg MT/kg that had been stored in a dark freezer (January 30 to December 1, 1995); and
3) a feed sample containing 60 mg MT/kg stored for two months in the refrigerator followed by 54 days (equivalent to 26 days of storage followed by 28 days of use while sex reversing fry) at tropical ambient temperature, followed by an additional 189 days in the freezer (May 25 to December 1, 1995).

Data collection

A randomized complete block design consisting of seven treatments and four replicates per treatment was used. Maximum and minimum water temperatures and morning dissolved oxygen were recorded daily; Secchi disk visibility was recorded weekly. Data on daily growth, feed conversion, length, and weight were collected weekly and on the day following the final day of treatment. Survival was determined by counting the fry by weight the day after the last day of treatment. Treatment means for survival, feed conversion, length, weight, and percent males were compared using one-way analysis of variance (ANOVA).

Results and Discussion

Feed storage conditions of MT-treated rations had no effect on efficacy of sex reversal. *O. niloticus* populations receiving non-treated feed averaged 49.5% males. Populations greater than 98% males were produced with MT-treated feeds that had been stored under all of the described storage times (Table 1). Fry received the equivalent of 1.1 to 1.9 µg MT/g fish/d.

Storage time did not have an adverse effect on growth, survival, or feed conversion ratio (FCR) ($p > 0.05$; Table 2). Feed conversion ratios ranged from 0.85 to 0.87 across treatments. FCRs in other sex reversal studies have ranged from 1.0 to 1.3 (Phelps and Cerezo, 1993). Low FCRs in this study may be attributed to the lack of available, natural foods for the fry. Schroeder (1983) concluded that 50 to 70% of the growth of *O. aureus* hybrids came from natural food organisms. Storage durations apparently did not degrade nutrient quality sufficiently to affect food consumption; any deficiencies in feed quality were possibly supplemented by natural foods. At the end of the 28-day treatment period fish averaged 0.9 g. In other studies, average fry weights at the end of 21-28 days of treatment in hapas suspended in outdoor tanks and ponds ranged from 0.25 to 0.72 g (Buddle, 1984; Popma, 1987; Guerrero and Guerrero, 1988).

Table 2. Initial and final body weights, lengths, survival, and feed conversion ratios (FCR) of *Oreochromis niloticus* fry reared in 0.5-m^3 hapas. A diet with 17*a*-methyltestosterone and stored for different numbers of days in a refrigerator (refrig.) and at tropical ambient temperature (AT) (0 d-0 d, 0 d-7 d, 0 d-26 d, 60 d-0 d, 60 d-7 d, 60 d-26 d- or a control diet (non-treated) was fed to the fry for 28 days. Data are presented as means of 4 replicates.

	Refrigerate AT						
	Control	*0 d -0 d*	*0 d -7 d*	*0 d -26 d*	*60 d - 0 d*	*60 d - 7 d*	*2 d - 26 d*
INITIAL*							
Weight (g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Length (mm)	10.4	10.4	10.4	10.4	10.4	10.4	10.4
FINAL							
Weight (g)	0.9	1.0	0.9	0.9	0.8	0.9	0.9
Length (mm)	36.0	37.0	36.1	36.3	35.0	36.0	35.9
% Survival	55.3	59.5	54.1	57.0	61.0	63.0	58.0
FCR	0.9	0.8	0.9	0.8	0.8	0.8	0.8

* No significant (P > 0.05, ANOVA) differences were observed among treatments for any parameter.

Methyltestosterone concentration was relatively stable. Initial hormone concentration in the feed was 60.4 mg MT/kg of feed; hormone concentration, after two months of refrigerator storage plus 26 days on the shelf was 54.8 mg MT/kg of feed. Factors that influence the degradation of MT include temperature and light sensitivity; however, these factors did not affect MT-feed concentrations in this study.

Initial peroxide value was 13 meq peroxide/kg feed for the feed stored in the freezer; feed stored for two months in the refrigerator plus 26 days at tropical ambient temperature was 20 meq/kg feed. Feeds with peroxide values between 3 and 30 meq/kg/feed are classified as having some oxidation but are not rancid.

The National Research Council (1981) reported that feed stored in an area with high moisture and/or high temperatures will cause peroxidation of the lipid and degradation of vitamins. Results indicate that storage times of up to two months in the refrigerator followed by 26 days at tropical ambient temperature do not cause adverse effects on the efficacy of *O. niloticus* fry sex reversal in an outdoor environment. Varadaraj (1994) found that 100% male tilapia were produced when given feed (stored in a light-proof desiccator) mixed with MT which had been stored for 11 days at room temperature in a light-proof desiccator. He found that only 54% males were produced when fry were given feed prepared with MT which had been stored at room temperature and had been exposed to light and air, despite past-preparation storage of the MT-treated feed at 4°C in a light-proof dessicator. Only 55% males were produced when fry were given MT-treated feed, which had been stored at room temperature, exposed to light and air, and prepared with MT stored at room temperature in a light-proof dessicator.

Conclusions

MT storage times of up to 60 days in the refrigerator followed by 26 days at tropical ambient temperature did not affect growth, survival, feed conversion efficiency, or sex reversibility in *O. niloticus* fry fed a hormone-containing diet of 60 mg MT/kg for 28 days. Greater than 99% males were produced after fry were fed with feeds stored under six different regimes. After 60 days in the refrigerator followed by 26 days at tropical ambient temperature, feeds were not rancid (final peroxide value of 20 meq/kg feed), and MT levels were reduced from 60.4 mg MT/kg feed to 55.0 mg MT/kg feed.

Literature Cited

Abdelhamid, A.A., 1988. Genetic homogeneity of seven populations of *Tilapia nilotica* in Africa, Central America, and Southeast Asia. M.S.

Thesis. Auburn Univ., AL 53 pp., Philipp. Dev. VII (14):20-25.

Association of Official Analytical Chemists (AOAC), 1990. Peroxide value of oils and fats (965.33). In: K. Helrich (Editor), Official Methods of Analysis, 15th Edition. AOAC Inc. Inc., Arlington, VA, pp. 956-957.

Bligh, E.G. and W.J. Dyer, 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol., 37:911-917.

Budavari, S., M.J. O'Neil, A. Smith, and P.E. Heckelman (Editors), 1989. Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals, 11th Edition. Merck and Co., Rahway, New Jersey, 1463 pp.

Buddle, C.R., 1984. Androgen-induced sex-inversion of *Oreochromis* (Trewavas) hybrid fry stocked into cages standing in an earthen pond. Aquaculture, 40:233-239.

Feldman, D.J. Gagon, R. Hofmann, and J. Simpson, 1988. Statview SE + Graphics (software). Abacus Concepts, Inc., Berkeley, California.

Folch J., M. Lees, and G.H. Sloane Stanley, 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem., 226:497-509.

Guerrero, R.D., and L.A. Guerrero, 1988. Feasibility of commercial production of sex-reversed Nile tilapia fingerlings in the Philippines. In: R.S.V. Pullin, T. Bhukaswan, K. Tonguthai, and J.L. Maclean (Editors), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 183-186.

Guerrero, R.D. and W.L. Shelton, 1974. An acetocarmine squash method for sexing juvenile fishes. Prog. Fish-Cult., 36:56.

Hepher and Pruginin, 1981. Commercial Fish Farming. John Wiley and Sons, New York, 291 pp.

Hickling, C.F., 1963. The cultivation of tilapia. Scientific American, 208(5):143-153.

Jauncey, K. and B. Ross, 1982. A Guide to Tilapia Feeds and Feedings. Institute of Aquaculture, University of Stirling, Scotland, 111 pp.

National Research Council, 1981. Nutrient Requirements of Coldwater Fishes. National Academy of Sciences, Washington, D.C., 63 pp.

Nakamura, M. and M. Iwahashi, 1982. Studies on the practical masculinization in *Tilapia nilotica* by the oral administration of androgen. Bull. Jpn. Soc. Sci. Fish., 486:763-769.

Nakamura, M. and Takahashi, H., 1973. Gonadal sex differentiation in *Tilapia mossambica* with special regard to the time of estrogen treatment effectiveness in inducing feminization of genetic fishes. Bull. Fac. Fish., Hokkaido University, 24:1-13.

Pandian, T.J., and K. Varadaraj, 1987. Techniques to regulate sex ratio and breeding in tilapia. Current Science (Bangalore), 56:337-343.

Pandian, T.J., and K. Varadaraj, 1988. Techniques for Producing all-male and all-triploid *Oreochromis mossambicus*. In: R.S.V. Pullin, T. Bhukaswan, K. Tonguthai, and J.L. Maclean (Editors), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 243-249.

Phelps, R.P. and G. Cerezo, 1992. The effect of confinement in hapas on sex reversal and growth of *Oreochromis niloticus.* Journal of Applied Aquaculture, 4:73-81.

Popma, T.J., 1987. Freshwater fishculture development project-ESPOL, Guayaquil, Ecuador. Final Technical Report. Auburn University, Alabama, 75 pp.

Schroeder, G.L., 1983. The role of natural foods in tilapia growth: A study based on stable isotope analysis. Proceedings of the International Symposium on Tilapia in Aquaculture, 8-13 May 1983, Nazareth, Israel, pp. 313-322.

Shelton, W.L., K.D. Hopkins, and G.L. Jensen, 1978. Use of hormones to produce monosex tilapia for aquaculture. In: R.O. Smitherman, W.L. Shelton and J.H. Grover (Editors), Symposium on the Culture of Exotic Fishes. Fish Culture Section, American Fisheries Society, pp. 10-13.

Shelton, W.L., R.D. Guerrero, and J. Lopez-Macias, 1981. Factors affecting androgen sex reversal of *Tilapia aureus*. Aquaculture, 25:59-65.

Sigma Chemical Company, 1994. Material Safety Data Sheet. St. Louis, MO, USA, 2 pp.

Soliman, A.K., R.J. Roberts, and K. Jauncey, 1983. The pathological effects of feeding rancid lipid in diets for *Oreochromis niloticus.* In: L. Fishelson and Z. Yaron (Editors), International Symposium on Tilapia in Aquaculture, Nazareth, Israel. Tel Aviv University, Tel Aviv, Israel, pp. 193-199.

Syndel Laboratories Ltd., 1993. High-performance liquid chromatography (HPLC) with UV detection. Syndel Laboratories Ltd., Vancouver, B.C., 2 pp.

Varadaraj, K., S.S. Kumari, and T.J. Pandian, 1994. Comparison of conditions for hormonal sex reversal of Mozambique tilapias. Prog. Fish. Cult., 56:81-90.

Vera Cruz, E.M. and G.C. Mair, 1994. Conditions for effective androgen sex reversal in *Oreochromis niloticus.* Aquaculture, 122:237-248.

Zeigler, Inc., personal communication, October 31, 1995.

Reproductive Efficiency, Fry Growth, and Response to Sex Reversal of Nile and Red Tilapia

Interim Workplan, Africa Study 6

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Introduction

The red color pattern in some strains of tilapia has added commercial value in some markets. Although red tilapia may be more marketable, questions have arisen regarding its value as a culture fish. El Gamal (1987) reported that during growout from 130 to 262 g, a red strain of tilapia had significantly lower survival than *Oreochromis aureus x Oreochromis aureus* and *Oreochromis niloticus x Oreochromis niloticus. O. niloticus* have shown superior growth during the sex-reversal phase compared to red tilapia (Berger and Rothbard, 1987). Red females produced the same number of fry per kg of body weight as *O. niloticus* females (El Gamal, 1987).

In the following study, *Oreochromis niloticus* and a red x red (RT x RT) strain were compared in terms of fecundity of brood females and efficacy of sex reversal.

Materials and Methods

Research for these studies was conducted in two phases at the El Carao National Fish Culture Research Center, General Directorate of Fisheries and Aquaculture, Ministry of Natural Resources, Comayagua, Honduras.

Phase I-Broodstock Fecundity

Red tilapia broodstock were identified electrophoretically as 80% *O. niloticus,* 12% *O. aureus,* and 8% *O. mossambicus.* All 11 loci examined were contaminated to some degree. Analyses were conducted by Fishery Information Management Systems, Auburn, Alabama, using starch-gel electrophoresis (McMandrew and Majumdar, 1983; Macaranas et al., 1986; Brummett, 1986). Only red broodstock were used for reproduction trials. Red brooders were a light, pinkish-red color with an occasional black spot near the operculum.

Nile tilapia (*O. niloticus*) from Auburn University were introduced to El Carao Station in 1977. In 1988 they were identified using horizontal starch-gel electrophoretic techniques (Abdelhamid, 1988), as 90% *O. niloticus* with four contaminated loci:

- GPI-A from *O. mossambicus*,
- ACP-B from *O. mossambicus* or *O. hornorum*,
- SOD-A from *O. mossambicus* or *O. hornorum*, and
- MDH-A from *O. mossambicus* or *O. hornorum* or *O. aureus*.

Seed Production

Four 0.05-ha ponds were filled with reservoir water two to three days prior to stocking. Two ponds were stocked with red broodfish and two ponds with Nile tilapia broodfish per trial. Prior to stocking, a sample of 25 males and 25 females from each group were weighed and measured to calculate Fulton's Condition Factor (Anderson and Gutreuter, 1983). Two hundred and thirty females and 115 males were stocked into each pond (882 -1,554 kg/ha). The mouth of each female was checked for eggs or fry at stocking. Broodfish were fed a 25% protein ration once daily at a rate of 1% body weight per day. Maximum and minimum water temperature and morning dissolved oxygen were recorded daily; secchi disk visibility was recorded weekly.

Fry were collected 215 to 230 degree-days after stocking (13-19 days) according to Green and Teichert-Coddington (1993) by draining ponds into a concrete harvest sump in which water was 30-cm deep. The fry were skimmed off the water surface with a large, square-framed, fine-mesh net. Fry were graded through a 3.2-mm vexar screen (Hiott and Phelps, 1993). Fry were counted and sorted into two separate groups: those retained by the grader (> 14 mm) and those that passed through the grader (≤ 14 mm).

Broodfish were collected with hand nets, separated by sex, counted, and weighed. Brooders were held by sex in 20-m^3 concrete tanks and fed at 1.5% body weight per day for seven to ten days prior to restocking. Each spawning pond was thoroughly dried and prepared for refilling. The trial described was repeated four times during a six month period.

Fry were counted by visual comparison to a standard of 500 fry. Subsamples of 25 to 50 fry were measured to the nearest millimeter at the beginning, middle, and end of counting. Direct counts of individuals were taken to determine mortality of fry after harvesting.

A 2 x 4 factorial design, consisting of two treatments and four trials over time, was used; trials were replicated twice per fish type. Treatment means for average weight, number of fry produced, number of fry per kilogram, number of fry per female, length, growth rate, and survival were compared using two-way analysis of variance (ANOVA). Correlations between number of fry and male:female weight ratio, male:female sex ratio, female weight, male weight, condition factor, and temperature were analysed by regression. All statistical analyses were made using a Statview + Graphics program (Feldman et al., 1988).

Phase II: Sex Reversal

Nile tilapia and red fry, 10.4 and 9.4 mm (standard length), respectively, were harvested from Phase I spawning ponds, stocked into hapas suspended from a wooden pier in a 0.1-ha pond with a maximum depth of 1.2 m and a minimum depth of 0.7 m. The hapas measured 1.0 m x 1.0 m x 0.7 m (length x width x height) and contained 0.5 m^3 of water. Fry were counted by visual comparison and stocked at 4,000/m^3 as recommended by Vera Cruz and Mair (1994). When the red fry were stocked, the percentages of red- and wild-colored (black) fry were recorded.

A diet containing 60 mg of 17a-methyltestosterone (MT)/kg of feed recommended by Mair and Little (1991) was prepared according to Zeigler, Inc. methods (personal communication, 1995). The hormone additive was prepared by dissolving 3 g of the steroid in 1,000 ml of 95% ethyl alcohol to make a stock solution of 3 mg MT/ml. The stock solution was stored in a refrigerator at 4°C. Twenty milliliters of the stock solution were added to 210 ml of 90% ethyl alcohol and then sprayed over each kilogram of feed. The feed Zeigler Mash contains 55% protein, 13% carbohydrate, 15% fat, 8-10% moisture content, 8-9% ash, and < 1% fiber. The feed was sprayed in a covered mixer and thoroughly mixed for 20 minutes. Three kg of feed were prepared per batch. The feed was spread in a 5-cm deep layer on a table inside the laboratory at 26°C for 12 hours to allow the solvent to evaporate . The next day the feed was sealed hermetically in plastic zip-lock bags and placed in a freezer at -2°C.

Table 1. Body weight and standing crop of red and Nile tilapia brooders stocked in 0.05-ha ponds from February to July. Data are means of two replicates per trial.

	Avg. Wt. (g)		Standing Crop (kg/ha)	% Survival at Harvest	No. of Fry Harvested	Condition Factor
	Females	*Males*				
TRIAL 1						
Red	136	238	1,092	99.9	33,548	1.6
O. niloticus	120	234	1,024	99.9	36,704	1.6
TRIAL 2						
Red	122	240	1,027	99.9	58,000	1.6
O. niloticus	106	230	976	99.9	55,250	1.6
TRIAL 3						
Red	133	291	1,243	99.9	107,750	1.6
O. niloticus	111	224	1,011	99.9	75,900	1.6
TRIAL 4						
Red	174	338	1,548	99.9	136,000	1.6
O. niloticus	104	266	1,073	99.9	93,500	1.6
GRAND MEAN						
Red	141 *	277 *	1,228	99.9	83,825	1.6
O. niloticus	110 *	238 *	1,021	99.9	65,339	1.6

* Values in the same column are significantly different ($P < 0.05$).

Daily feed quantities were removed from storage, weighed the morning of feeding, and placed in sealed, clear, plastic jars. The jars were held outdoors in white plastic containers next to their designated hapas on the pier of the pond until use. Maximum and minimum water temperature and morning dissolved oxygen (0600) were recorded daily and secchi disk visibility was recorded weekly. Fry were fed four times daily (0800, 1000, 1300, 1600 h) for 14, 21, or 28 days. Feed was placed in 60-cm feeding rings with trays suspended underneath. The feeding rate was adjusted weekly by measuring 25 fish per hapa to the nearest millimeter, and biomass was estimated using the formula described by Shelton et al. (1978). Daily feeding rates were 15, 12, 8 and 4% body weight during weeks 1, 2, 3 and 4, respectively.

After 14, 21, or 28 days of hormone treatment, fry were harvested, weighed, and counted. One hundred individuals from each replicate were randomly selected and measured to the nearest mm to determine length-frequency distribution.

Five hundred fry from each replicate were returned to the hapa and grown to a size of at least 4 cm (58 days of culture post-treatment), harvested, and then preserved in formalin. The sex of 100 fish per replicate was determined using the gonadal squash method (see Guerrero and Shelton, 1974). Gonads containing both ovarian and testicular tissue were classified as "intersex". To determine intersex gonads, the percentage of ovarian tissue within the length of the gonad was estimated.

The experimental design was a 2 x 4 factorial with two fish types and four treatments. Treatment means for average weight, length, survival, feed conversion ratio, and percent males were compared by two-way analysis of variance (ANOVA). Feed conversion ratio equals the amount of feed given divided by the weight gain of the fish. Difference

Table 2. Number of Red and Nile tilapia fry female per kg of female and by size class harvested from 4 trials from February to July in Comayagua, Honduras. Data are as means of two replicates per trial.

	No. Fry/kg Female	No. Fry/ Female	No. Fry < 14 mm	No. Fry ≥ 14mm	Mean Water Temperature	Degree-Days to Harvest	Percent Red Fry
TRIAL 1							
Red	1,155	158	32,298	1,250	25	221	74
O. niloticus	1,440	172	36,388	316	25	218	
TRIAL 2							
Red	2,427	297	57,250	750	30	228	77
O. niloticus	2,362	249	54,500	750	30	225	
TRIAL 3							
Red	3,820	506	105,500	2,250	30	232	84
O. niloticus	3,048	336	74,750	1,150	30	231	
TRIAL 4							
Red	3,468	603	134,500	1,500	29	225	73
O. niloticus	3,952	410	93,000	500	31	226	
GRAND MEAN							
Red	2,718	391	82,387 *	1,438 *	29	227	77
O. niloticus	2,701	292	64,659 *	679 *	29	225	

* Values in the same column are significantly different (P < 0.05).

among treatments was detected using Fisher PLSD and Sheffe F-test ($p < 0.05$). All statistical analyses were made using a Statview + Graphics program (Feldman et al., 1988).

Results and Disscussion

Phase 1-Reproduction

Minimum and maximum water temperature during the trials ranged from 21.0 to 36.0°C. Cumulative degree-days (Pruess, 1983) per trial ranged from 218 to 232 with a mean of 225.8. Green and Teichert-Coddington (1993) recommend that for maximum production of fry less than 14 mm long, harvest should be between 195 and 220 degree-days. Both RT x RT and Nile tilapia conformed well to these guidelines, producing a total of 329,548 and 258,638 fry less than 14 mm with 0.01% of the total fry production being greater than 14 mm for all four trials (Table 1). Morning dissolved oxygen never fell below 2.5 mg/l. and disease outbreaks did not occur.

The mean survival rate for female RT broodstock was 94.8% and 96.3% for males in all four trials. The mean survival for Nile tilapia was 96.4% for females and 98.3% for males. Teichert-Coddington et al. (1993) suggested that RTxRT brood tilapia may have reduced survival due to their susceptibility to predation and handling; however, in this study red and Nile tilapia broodstock had similar survival (Table 1).

There was a significant difference between mean average weight of females; female average weight also increased with time ($p = 0.01$). Mean average weight for red females was 141.3 g, and 109.9 g for Nile tilapia females. Mean average weight for red males was 276.6 g, and 238.2 g for Nile tilapia males (Table 2). RT x RT and Nile tilapia broodstock had a similar condition factor. A similar number of females was used from trial to trial, but due to weight changes female standing crops differed from trial to trial. The number of fry produced was not correlated to standing crop ($R^2 = 0.18$; $p = 0.12$) over a range of standing crops from 976 kg/ha to 1548 kg/ha (Table 1). Sex ratio did not change from trial to trial and had no effect on the number of fry produced ($p = 0.37$).

Both brood types had similar fecundities (Table 2), averaging 2,718 fry per kg of female for RT x RT and 2,701 fry per kg of female Nile tilapia. Fecundity was not correlated to female weight in either species when female weights ranged from 122 to 174 g and 104 to 120 g during the four trials for RT x RT and Nile tilapia, respectively ($R^2 = 0.23$; $p = 0.22$). The RT broodfish produced an average of 72.7% red-colored fry, while 27.3% fry had a wild-color pattern. El Gamal (1987) found no difference in number of eggs per kg of female body weight in *O. niloticus* and *O. aureus* over a weight range of 103 to 172 g. No difference in numbers of fry produced per kg of female body weight was also reported by Dazdzie (1970) and Sunusi (1984).

The total number of fry produced differed significantly between trials ($p = 0.002$). Fry number was positively correlated to male:female weight ratio ($R^2 = 0.39$; $p = 0.001$), degree-days ($R^2 = 0.51$; $p = 0.002$), and water temperature ($R^2 = 0.58$; $p = 0.0006$). There was, however, a stronger relationship to fry increase by trial ($R^2 = 0.85$; $p = 0.0001$). Trial 1 had an average water temperature of 25°C, while trials 2, 3 and 4 were conducted at temperatures ranging from approximately 29 to 31°C.

Analysis by trial indicated that fry production was not correlated to male:female weight ratio, female weight, or degree-days, but there was some correlation to male weight ($R^2 = 0.31$; $p = 0.01$). Fry production was not correlated to male or female condition. Guerrero and Guerrero (1985) reported that increase in fry numbers (absolute number) was due to increased size of females, but that was not the case in this study. There was no difference in fecundity by brood type at 30°C.

A possible explanation for the increase in fry production over time may be that territory and social hierarchy of the broodstock were previously established by a group in previous trials. At the start of these trials the brooders had been held in earthen ponds undisturbed for one month. They were then harvested and separated by sex, held in 20 m^3 concrete tanks, and fed a complete ration (30% protein) at 1.5% body weight per day for 10 days. Between trials the broodfish were separated by sex, held for 7 to 10 days, and fed 1.5% body weight per day. During the four trials 95% of the broodfish were restocked. Little (1989) reported improved synchrony of spawning in hapas when spawned females were conditioned in hapas and then again spawned after conditioning.

Phase II: Sex Reversal

The average percentage of males in control groups was 48.3% for *O. niloticus* and 46.0% for red fry. El Gamal (1987) reported that sex ratios of red tilapia were skewed consistently toward males and that sex ratios for normally-pigmented fish were highly variable. Sex ratio for the red strain used in this study was not skewed. The interaction between species and days of feeding did not affect the percentage of males produced. Hormone-treated Nile tilapia and RT x RT fry had similar percentages of males (Table 3). Fry of Nile tilapia were 85, 92, and 82% male after 14, 21, and 28 days of hormone treatment, respectively. RT x RT fry were 85, 83, and 87% male after 14, 21, and 28 days of treatment, respectively. Treatment durations of 14 to 28 days resulted in similar percentage of males for both types of fry. The overall percentage of males produced was lower than expected, particularly for the 21- and 28-day treatments. Berger and Rothbard (1987) produced 97.3 and 99.7% males when fry were fed 17-ethynyltestosterone (17-ET) at a rate of 60 and 120 mg 17-ET/kg for 28 days, respectively. McGeachin et al. (1987) concluded that excessive doses of MT (60-120 mg/kg feed) for 22 days did not produce abnormalities or affect survival or sex reversal in *O. aureus*.

There was no significant difference between the percentage of intersex fish produced in red and *O. niloticus* fry based on the length of treatment period ($p > 0.05$). There were 3, 1 and 0% intersex fish for red fry and 10, 2, and 6% intersex fish for *O. niloticus* fry treated for 14, 21 and 28 days, respectively (Table 3). Watanabe et al. (1991) reported 1.5% intersex fish produced during a hormone treatment of red tilapia which resulted in 94.3 to 98.1% males.

Fry in each hormone treatment received a similar quantity of hormone during the treatment period. Fry received an average of 1.7 µg MT/g fish/d for 28 days. There was a correlation between the percentage of male fry and the quantity of hormone fed fry/d ($R^2 = 0.3$; $p = 0.003$). Pandian and Varadaraj (1988) reported 100% masculinization of *O. mossambicus* fry when fry received 1.5 µg/g fish/d for a duration of 11 days. Varadaraj et al. (1994) found that fry treated with 5 or 10 mg MT/kg diet produced 100% males.

Table 3. Sex composition of red and Nile tilapia fry fed a diet treated with 60 mg 17 α-methyltestosterone/kg diet for 14, 21, and 28 days. Data are based on means of four replicates (100 fish/replicate). No significant differences ($p > 0.05$) were observed among treatments for any parameter.

Species	Duration of Androgen Treatment (d)	% Males	% Females	% Intersex	Total No. of Fish Sexed
Red x Red	0	46	54	0	400
O. niloticus	0	48	52	0	300
Red x Red	14	85	12	3	400
O. niloticus	14	85	5	10	400
Red x Red	21	83	16	1	400
O. niloticus	21	92	6	2	400
Red x Red	28	87	13	0	400
O. niloticus	28	82	10	6	400

Red and Nile tilapia fry fed MT for 14, 21, or 28 days showed no significant difference in mean survival ($p > 0.05$, Table 4). El Gamal (1987) reported a difference in survival between red (*Oreochromis* spp.) and *O. niloticus* and *O. aureus* fry ($p = 0.05$). A comparison of red-colored and wild-colored (black) fry within the red treatments revealed that red fry comprised 73% of the initial population and 69% of the total population at harvest. No significant difference between red and *O. niloticus* fry were found when FCR or growth were compared ($p > 0.05$, Table 4). Wild-colored (black) and red fry within the "red" groups did not differ in length after 28 days of treatment. El Gamal (1987) reported that red fish consistently had a lower average weight gain than their normally pigmented siblings.

Table 4. Average length (mm), mean individual weilght (g), mean net weight per treatment (g), percent survival and food conversion ratio for red tilapia and Nile tilapia fry fed hormone treated feed for 14, 21, and 28 days. Data are means of 4 replicates. No significant differences ($p > 0.05$) were observed among treatments for any parameter.

	Total Length (mm)	Weight Fish (g)	Net Weight (g)	% Survival *	FCR
DAY 14					
Red x Red	20.0	0.2	322	96	0.6
O. niloticus	22.1	0.2	334	84	0.5
DAY 21					
Red x Red	27.0	0.4	524	65	0.8
O. niloticus	27.3	0.4	571	78	0.7
DAY 28					
Red x Red	32.1	0.6	817	69	0.8
O. niloticus	32.7	0.7	979	78	0.8

* Survival to the end of hormone treatment period.

Conclusion

The red color variant of a predominately *O. niloticus* strain had similar fecundity to wild-colored *O. niloticus*. Broodstock survival, fry per kg female, and overall numbers of fry produced were similar. Fry production increased over time but was not correlated to male:female weight ratio, broodstock condition, or female weight. Increase in fry production from trial to trial was possibly related to decreased territorial conflicts due to a social hierarchy established by a group during previous trials.

Literature Cited

Abdelhamid, A.A., 1988. Genetic homogeneity of seven populations of *Tilapia niloticus* in Africa, Central America, and Southeast Asia. M.S. thesis, Auburn University, AL, USA, 53 pp.

Anderson, R.O. and S.J. Gutreuter, 1983. Length, weight, and associated structural indices. In: L.A. Nielson and D.L. Johnson (Editors), Fisheries Techniques. American Fisheries Society, Bethesda, Maryland, pp. 283-300.

Berger, A., and S. Rothbard, 1987. Androgen induced sex-reversal of red tilapia fry stocked in cages within ponds. Bamidgeh, 39:49-57.

Brummett, R.E., 1986. Effects of genotype x environment interaction on growth, variability, and survival of improved catfish. Ph.D, Dissertation, Auburn Univ., Alabama, USA, 107 pp.

Dazdzie, S., 1970. Laboratory experiment on the fecundity and frequency of spawning in *Tilapia aureus.* Bamidgeh, 22(1):14-18.

El Gamal, A.R., 1987. Reproductive performance, sex ratio, gonadal development, cold tolerance, viability, and growth of red and normally pigmented hybrids of *Tilapia aureus* and *Tilapia niloticus.* Ph.D. Dissertation, Auburn University, AL, USA, 111 pp.

Feldman, D., J. Gagon, R. Hofmann, and J. Simpson, 1988. Statview SE + Graphics. Abacus Concepts, Inc., Berkeley, California.

Green, B.W. and D.R. Teichert-Coddington, 1993. Production of *Oreochromis niloticus* fry for sex reversal in relation to water temperature. Journal of Applied Ichthyology, 9:230-236.

Guerrero, R.D., III and L.A. Guerrero, 1985. Effect of breeder size on fry production of Nile tilapia in concrete pools. Trans. Nat. Acad. Sci. and Tech. (Phils.), 7:63-66.

Guerrero, R.D. and W.L. Shelton, 1974. An acetocarmine squash method for sexing juvenile fishes. Prog. Fish-Cult., 36:56.

Hiott, A.E. and R.P. Phelps, 1993. Effects of initial age and size on sex reversal of *Oreochromis niloticus* fry using methyltestosterone. Aquaculture, 112:301-308.

Little, D.C. 1989. An evaluation of strategies for production of Nile tilapia *(Oreochromis niloticus)* fry suitable for hormonal treatment. Ph.D Thesis, Institute of Aquaculture, University of Stirling, Scotland, 111 pp.

Macaranas, J.M., N. Taniguchi, M.J.R. Pante, J.B. Capili, and R.S.V. Pullin, 1986. Electophoretic evidence for extensive gene introgression into commercial *Oreochromis niloticus* (L.) stocks in the Philippines. Aquaculture and Fisheries Management, 17:249-258.

Mair, G.C. and D.C. Little, 1991. Population control in farmed tilapia. NAGA, ICLARM Quarterly, Manila, Philippines 14(3):8-13.

McAndrew, B.J. and K.C. Majumdar, 1983. Tilapia stock identification using electrophoretic markers. Aquaculture, 30:249-261.

McGeachin, R.B., E.H. Robinson, and W.H. Neil, 1987. Effect of feeding high levels of androgens on the sex ratio of *Oreochromis aureus*. Aquaculture, 61: 317-321.

Pandian, T. J., and K. Varadaraj, 1988. Techniques for producing all-male and all-triploid *Oreochromis mossambicus*. In: R.S.V. Pullin, T. Bhukaswan, K. Tonguthai, and J.L. Maclean (Editors), Second International Symposium on Tilapia in Aquaculture. International Center for Living Aquatic Resources Management. Conference Proceedings 15, Manila, pp. 243-249.

Pruess, K.P., 1983. Day-degree methods for post management. Environ. Entomol., 12:613-619.

Shelton, W.L., K.D. Hopkins, and G.L. Jensen, 1978. Use of hormones to produce monosex tilapia for aquaculture. In: R.O. Smitherman, W.L. Shelton, and J.H. Grover (Editors), Symposium on the Culture of Exotic Fishes. Fish Culture Section, American Fisheries Society, pp. 10-13.

Sunusi, H. 1984. Effects of relative size of females and males on spawning success in *Tilapia niloticus.* M.S. thesis, Auburn University, AL, USA, 31 pp.

Teichert-Coddington, D.R., B. Green, C. Boyd, 1993. Substitution of inorganic nitrogen and phosphorus for chicken litter in production of tilapia. In: H.S. Egna, M. McNamara, J. Bowman, and N. Astin (Editors), Tenth Annual Administrative Report, PD/A CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 19-27.

Varadaraj, K., Sindho-Kumari, and T.J. Pandian, 1994. Comparison of conditions for hormonal sex reversal of mozambique tilapias (*Oreochromis mossambicus*). Prog. Fish. Cult., 56(2):81-90.

Vera Cruz, E.M. and G.C. Mair, 1994. Conditions for effective androgen sex reversal in *Oreochromis niloticus.* Aquaculture, 122:237-248.

Watanabe, W.O., J.H. Clark, J.B. Dunham, R.I. Wicklund, and B.I. Olla, 1991. Culture of Florida red tilapia in marine cages: The effect of stocking density and dietary protein on growth. Aquaculture, 90:12-134.

Zeigler, Inc., Personal Communication, October 31, 1995.

African Site Evaluation and Development Planning

Interim Work Plan, Africa Study 1

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Introduction

Under Work Plan 7, Study C, a site-selection strategy was developed to begin the process of replacing the site at Rwasave, Rwanda. That site was lost because of the outbreak of war and civil violence in 1994. To guide data collection, fifteen site evaluation criteria were developed with assistance from the ME and Technical Committee of the PD/A CRSP. USAID site-selection criteria were incorporated into the process.

Additional site visits were accomplished and developed into formal evaluations under the present study. The Sagana Fish Culture Farm in Kenya was recommended as a prime site during the PD/A CRSP Annual Meeting in January 1996. A proposal to develop a CRSP site at Sagana in cooperation with the Kenya Ministry of Tourism and Wildlife and its Department of Fisheries was submitted to the government of Kenya. A development plan for that station was also outlined.

Materials and Methods

The following outlines the strategy for site evaluation:

- Establish site evaluation criteria with input from the Technical Committee and include criteria found in the BIFAD guidelines.
- Gather information on potential sites from CRSP members, agency publications, interviews, USAID Strategic Objectives, USAID Missions, and other sources.
- Visit most promising sites, using the evaluation criteria as a template for gathering information in-country.
- Recommend a site after committee interaction.
- Submit the site recommendation to the ME for administrative review and to the Technical Committee for technical review.
- The final selection of the site will be made by the ME.
- Initiate the required Memoranda of Understanding with host country entities.

Activities conducted through September 1996:

- Spring, 1994: Developed country and site evaluation criteria.
- Summer, 1994: Reviewed USAID mission programs, mission closures, and mission strategic objectives.
- November, 1994: Visited Sagana Fish Culture Farm and sites in Mombasa, Kenya. The proposed visit to Malawi was delayed by USAID/Malawi.
- Spring, 1995: Prepared a preliminary proposal for involvement at Sagana, Kenya.
- Summer, 1995: Reviewed USAID '96 Congressional Presentations, with emphasis on strategic objectives (1995 strategic objectives for all sub-Saharan African countries had been reviewed in 1994).
- August, 1995: Consulted with Boyd Haight, of Aquaculture for Local Community Development Program, Food and Agriculture Organization (ALCOM/FAO), on potential aquaculture sites in the Southern Africa region.
- September, 1995: PD/A CRSP was contacted by Rwandan government regarding the re-establishment of a project at the Rwasave Station, Butare, Rwanda.
- September, 1995: Conducted a site evaluation in Niger following the InterCRSP workshop in Niamey, Niger.
- October, 1995: Consulted with ALCOM/FAO and SADC (Southern Africa Development Community) personnel during the ALCOM meeting in Harare, Zimbabwe.
- October, 1995: Conducted country/site evaluations in Zimbabwe and Kenya. During site evaluations in Kenya, the Sagana site and the Kibos site, near Kisumu, were visited.
- November, 1995: Consulted with ALCOM and SADC personnel in Lilongwe, Malawi, during ALCOM Technical Conference on extension.
- November/December, 1995: Conducted country/site evaluations in Malawi, Kenya, and Tanzania (Domasi, Bunda College, Sagana, Kingolwira, Sokoine University.)
- September, 1996: Evaluated Senegal and Ghana in conjunction with an InterCRSP meeting. Additional meeting attended with Kenyan officials to facilitate processing of our proposal.

In addition, information gathering included discussions with USAID personnel in Washington, DC and in each country visited, and with FAO and other aquaculturists familiar with Africa. We also searched the literature on aquaculture potential, research priorities, geo-climatic conditions, etc., for countries of interest in the extensive ALCOM library and other in-country sources.

Results

Step-by-step evaluations of the major sites investigated are available. The following summarizes the results of the evaluations:

The Sagana Fish Culture Farm, Kenya

Site Characteristics

This site appears to satisfy the selection criteria for a prime research site and is the most promising site. The farm is large and has more than enough pond space for CRSP activities—approximately 20 ha of 150 ha on the farm are ponds. It is well staffed with about 65 staff members on site. The water supply is reliable and abundant throughout the year. Some modification of facilities (i.e., reparation of ponds and chemistry lab) may be required, but work could begin with minimum delay. *Oreochromis niloticus* (Turkana origin, volcani strain) and *Clarias gariepinus* are presently at the station. Good opportunities exist for collaboration with both the Kenya Department of Fisheries and the Belgian Kenya Project, with potential to work with Kenyan universities and other projects in Kenya, including the Lake Basin Development Authority, and FAO.

This site reasonably represents the environmental conditions, specifically the geo-climatic factors in which tilapia are cultured across Africa. Approximately 45,000 ponds are reported to exist in Kenya, although 25,000 may be a better estimate of the number of ponds in operation. Subsistence-level, semi-intensive, and intensive aquaculture is practiced in Kenya. There is an extension service for aquaculture; however, management recommendations for semi-intensive pond aquaculture are lacking. Information regarding the profitability of aquaculture is also lacking.

Transportation to and from Kenya is relatively easy. Establishing a project in Kenya requires approval at several governmental levels; the Ministry of Finance and Ministry of Tourism and Wildlife have approved our preliminary proposal and the USAID Mission outlook is favorable.

Conclusions

Sagana Fish Culture Station was recommended as the African prime site during the Annual Meeting, and a proposal was submitted to the Kenyan Government.

Bunda College of Agriculture, Malawi

Site Characteristics

This site meets some but not all criteria for a companion site. Malawi is developing as an important regional center for aquaculture and offers opportunities to interact with countries within SADC, with ALCOM, ICLARM, (International Center for Living Aquatic Resource Management), and Malawian institutions. FAO's program through ALCOM is focused on SADC countries, thus a companion site within SADC opens collaborative opportunities across Africa.

A major drawback to working in Malawi is that *Oreochromis niloticus* cannot be used for culture. A large variety of other tilapias are available, although the two species commonly cultured (*O. shiranus and Tilapia rendalli*) are not important culture species in other African countries.

There is a possibility of conducting collaborative research at either Domasi and/or Mzuzu from the Bunda College site. A great deal of interest and enthusiasm exists at Bunda College, although the staff seems to have a heavy workload. The pond facilities at the College are adequate, but water supply is limited during the dry season.

Conclusions

Bunda College is recommended to be considered as a potential companion site.

The Domasi Experimental Fish Farm, Malawi

Site Characteristics

This site meets many of the criteria for a prime site; however, it is already the prime site for ICLARM. ICLARM may be interested in some level of collaboration although the designated ponds are small when compared to CRSP requirements (167 m^2), and chemical fertilizer work is discouraged. Additionally, Japan has already located a project there.

Conclusions

Domasi experimental Fish Farm is not recommended as either a prime or companion site at this time, although some collaborative work may be initiated if Bunda College is established as a companion site. The project, however, should maintain contact with ICLARM in Africa.

Kingolwira Aquaculture Center and Sokoine University of Agriculture, Morogoro, Tanzania

Site Characteristics and Conclusions

Presently neither of these sites are suitable for CRSP research; however, the potential for regional outreach in Tanzania is high. Kingolwira Aquaculture Center is still under development, and recently a new water system and four ponds were constructed at that site. These recent developments improve opportunities for collaboration at some level in the future.

Sokoine University is just beginning to develop an aquaculture program; there is much enthusiasm and the potential for collaboration is high. There is a possibility for comparative research of *O. niloticus* and *O. shiranus* and/or *T. rendalli* (culture species that are available in Malawi) at a small government station near Songea, not far from Lake Malawi. We recommend that the project continue to communicate with aquaculturists in Tanzania for potential future collaboration.

The Kibos Fingerling Production Center near Kisumu, Kenya

Site Characteristics

This site is a production, research, and training facility of the Lake Basin Development Authority. The Kibos Fingerling Production Center is at a higher elevation (1400 m) than Sagana, and both *Clarias* and tilapia (*O. niloticus*) are cultured here. Classroom facilities are available for presentations to extension agents and farmers. Efforts here are concentrated on *Clarias* reproduction and rearing and the extension of developed methodologies. The station is rather small with about 14 ponds in use; all water for the station is pumped from wells. The station emphasizes an intensified, small-scale aquaculture approach with extension as a major component. David Campbell of FAO is the Chief Technical Advisor for the Lake Basin Development Authority (LBDA), which operates Kibos. Thus, this site could potentially influence the large project area of the LBDA in Western Kenya near Lake Victoria.

Conclusions

This site is probably not suitable as a prime site because of facility limitations, water source, and overall size. It may be suitable as a companion site because studies and extension work there with tilapia and *Clarias* would complement the CRSP program. Its connection with the LBDA, FAO, UNDP, and the Belgian Survival Fund offers potential cooperative opportunities. If not a companion site, cooperation at this site at a less formal level may be beneficial. For the present, we recommend that Kibos be listed as a potential companion site.

Zimbabwe

Zimbabwe is no longer under consideration due to USAID Mission restrictions. In addition, drier climate and present drought conditions appear to decrease aquacultural potential. The presence of ALCOM offices in Zimbabwe is an incentive for continued communication with the ALCOM coordinator.

Other countries

Zambia—Not under consideration due to USAID Mission restrictions.

Uganda—Recently suggested to have high aquaculture potential; however, we have been unable to evaluate this site.

Niger—Visited in conjunction with another activity: very dry; low potential.

Guinea—Not under further consideration at present.

Ghana—A recent visit offered new encouragement to consider Ghana as a potential companion site. There appear to be good opportunities for collaboration, and the country has considerable potential to develop its aquaculture industry. An active governmental aquaculture development program is in place, and a potential site exists at Akosombo, near Volta Lake.

Discussion

The government of Kenya, through its Ministry of Finance and its Ministry of Tourism and Wildlife, recently approved our preliminary proposal and invited the PD/A CRSP Africa Project to submit a draft Memorandum of Understanding to formalize working relationships at the Sagana Fish Culture Farm. Collaboration with both the Kenya Department of Fisheries and the Belgian aquaculture project will have to be negotiated. USAID/Nairobi support is encouraging.

Development requirements at Sagana include the renovation of at least 12 ponds and the chemistry laboratory. The existing chemistry laboratory is small and requires remodeling for safety and functionality. Plentiful land space and water supply are positive factors for development requirements. All the Rwanda research and office equipment and the vehicle were lost in the war and need to be replaced. A preliminary list of needed items has been compiled.

Anticipated Benefits

Kenya offers a number of advantages as a prime site. It is a transportation and communications center for Eastern Africa, so communication, travel, shipping, and purchasing are simplified. Sagana Fish Culture Farm has plentiful water and land space and is located in an area supporting small-holder aquaculture. It would be an ideal location to manage companion or collaborating sites in locations such as Malawi, Ghana, or Tanzania. The process of site evaluation and characterization has opened opportunities for the PD/A CRSP Africa Project to cover a broad region across Sub-Saharan Africa. The continued allocation of resources and effort into collaboration with other sites should be encouraged to enhance the connections established during this study.

Risk Analysis of Optimal Resource Allocation by Fish Farmers in Rwanda

Work Plan Seven, Africa Study 7

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Introduction

The main objective of many small-scale fish farming projects in developing nations is to supply protein-rich food to rural people at reasonable prices and to provide them with limited but steady income and employment (Belsare 1986). Rwanda is a country characterized by subsistence agriculture and occurence of nutritional deficiencies. For example, across the country 37% of the total population consumes fewer calories than the minimum requirement, and 64% of the population is deficient in protein intake (World Bank, 1989). However, in some regions, caloric deficiencies are found in 82% of the population, and protein deficiencies are found in 85% of the population.

Surveys conducted in Rwanda showed that many small-scale fish farmers consider fish to be a cash crop. Findings by Engle et al. (1993) indicate that fish farming provides cash to a family in addition to supplementing the diet of Rwandan farmers. Molnar et al. (1991) and Engle et al. (1993) showed that fish production represents the main cash crop for over 50% of group members and private pond holders. Previous studies used partial farm analyses and economic engineering techniques to assess costs and return of fish production (Moehl, 1993; Engle et al., 1993).

Budget analysis is an important step in economics research, but it is a static analysis that does not take into account the following:

- factors such as fluctuations in prices, yields, and costs;
- farming system interactions in terms of labor, marketing, and resource constraints;
- social, economic, or welfare effects of the technology; and
- market factors.

A farmer's decision to adopt a new technology will depend upon these variables.

In many developing nations, the lack of comprehensive and appropriate data preclude whole-farm analysis that explicitly accounts for the types of factors involved. This study uses survey data from subsistence fish farmers in Rwanda to formulate a whole-farm model. This model will be used to analyze decision-making and resource allocation to meet the dual objectives of maximizing profit, while still satisfying the household's demand for food. The specific objective of this study was to determine farm plans that maximize returns to a representative Rwandan farm family's resources, subject to constraints of the farm family's proteinic and caloric requirements.

Materials and Methods

Model

A mathematical programming model was developed to determine optimal resource allocation on subsistence farms in Rwanda. The general form of the model was: maximize P = C _ X, subject to AX _ B, and x _ 0; where P is the objective function, C _ is a (1 x n) vector of coefficients associated with each activity, X is a (1 x n) vector of activities, A is an (m x n) matrix of technical coefficients, and B is an (m x 1) vector of constraints.

The primary objective of the model was to maximize net returns above variable cost while satisfying basic household nutritional needs. Production, sales, home consumption, and purchasing activities were included in the model. Thirteen different crops raised in the marais (valley bottomland in Rwanda where fish are raised) were modeled, including fish, sweet potatoes, Irish potatoes, cassava, taro, sorghum, maize, sweet peas, beans, soybeans, peanuts, rice, and cabbage. Data on crop yields, costs, and labor were obtained from Hishamunda (1993).

The principal factors that limited generation of cash income were land holdings, labor, and capital. Household nutritional requirements were modeled as requirements for the family to consume a minimum level of kilocalories of energy and grams of protein. Single balance rows were used for both energy and protein. Most crops are consumed fresh in Rwanda. Since there is little storage (other than for dried beans), storage activities were not included.

Separate models were developed for individually- and cooperatively-managed farms. Other scenarios included in the model were: 1) all enterprises with both protein and energy constraints; 2) all enterprises with protein constraints alone; 3) all enterprises with energy constraints alone; and 4) all enterprises without energy and protein constraints. The General Algebraic Modelling System (Brooke et al., 1992) was used to obtain solutions to the linear programming model. The quantities of fresh produce that could be sold from the farm at any given harvest were incorporated into the model as an additional marketing constraint because wholesale storage facilities are not available for fresh produce in Rwanda.

The risk programming model was based on Target MOTAD methodology (Hazell, 1971; Tauer, 1983; Watts et al., 1984). Risk variables included in the model were yield risk, price risk, and marketing risk. Decreasing levels of willingness to incur risk (or increasing levels of risk aversion) were incorporated into the model to provide insight into which management strategies are "best" for individuals who prefer lower levels of risk despite the fact that lower levels of risk generally result in lower levels of profit. See Tauer (1983) for details on modelling risk in economic analysis and methodologies to account for individual preferences regarding willingness to assume higher or lower levels of risk in farm management decision-making.

The model was validated following steps outlined in Hazell and Norton (1986). The validation process included comparisons of model results with existing data from the Rwandan Ministry of Agriculture and Forestry (Ministère de l'Agriculture, de l'Elevage et des Forêts, 1989) and the International Service for National Agriculture Research (ISNAR, 1992). Qualitative reviews by expatriates with long-term experience in extension activities with fish farmers in Rwanda were also incorporated into the validation process. As a result of the validation process, improvements were made to the model prior to developing the analyses presented in this paper.

Data

Data used in the analysis were taken from a cost of production survey of Rwandan fish farmers conducted in 1991 (Hishamunda et al., in press). A total of 267 completed questionnaires covering 10 of 11 prefectures in the country provided data to describe in detail sociodemographic, land, and labor allocation, along with relative cost characteristics of fish farmers' production systems.

All enterprises produced by cooperatives, with the exception of Irish potatoes, showed positive income above variable costs and positive net returns to land, labor, and management; however, fish farming yielded the highest income above variable costs (Table 1). Revenues generated from fish production included sale of both marketable-sized fish and fingerlings. If the sale of fingerlings was removed from revenue, fish production was the fourth most

Table 1. Estimated cost and returns for marais agricultural enterprises, Rwanda, 1995. Coop.: Cooperative respondent; Ind.: Individual respondent; $1 U.S. = 145 Rwandan Francs (RWF). Data regarding income above variable cost is from Hishamunda (1993).

Crop	Gross Receipts		Variable Cost		Income above Variable Cost[1]	
	Coop. (RWF)	*Ind.* (RWF)	*Coop.* (RWF)	*Ind.* (RWF)	*Coop.* (RWF)	*Ind.* (RWF)
Fish[2]	3,076	3,408	279	337	2,797	3,071
Sweet Potato	1,294	1,471	520	388	774	1,083
Irish Potato	1,275	2,103	1,607	1,789	-332	313
Cassava	1,080	1,160	365	955	715	205
Taro	855	960	288	403	567	557
Sorghum	810	540	325	154	485	386
Maize	1,175	925	407	424	768	501
Sweet Pea	-	400	-	302	-	98
Beans	1,360	920	393	414	967	506
Soybean	1,193	864	674	412	518	452
Peanuts	-	1,968	-	148	-	1,820
Rice	-	1,325	-	366	-	959
Cabbage	2,380	3,120	429	551	1,951	2,569

[1] Values for income above variable cost were taken from Hishamunda (1993).
[2] An additional 2.8 kg/ha and 3 kg/ha of fingerlings were produced in cooperatively- and individually-managed farms, respectively.

profitable enterprise following cabbage, peanuts, and sweet potatoes.

Labor values from survey data were used. Survey data included hours of labor per week for males, females, and children of different ages who participated in farm activities such as feeding, harvesting, and weeding. Mean values were used in the initial formulation, and minimum and maximum values were used to set bounds on sensitivity analyses. Household size averaged two adult members and one child for individually-managed farms, and cooperatives averaged 13 families with a range from 2 to 54 families participating in a fish cooperative.

Soybeans produced the most protein/hectare for both individually- and cooperatively-managed farms followed by beans (Table 2). Sweet potatoes produced the greatest amount of energy on individually-managed farms, and maize produced the highest amount of energy on cooperatively-managed farms.

Farm prices of some products varied considerably throughout the year, but the price of fish did not vary. To assess the effect of price seasonality, a data set that provided mean prices for various crops by month from 1986 to 1992 was obtained from the Service des Enquêtes et des Statistiques Agricoles (Clay, 1993). Marketing options that included different prices in different months were incorporated to account for seasonal price effects. Price data by "prefecture" for the period were used to examine differences among regions.

Results and Discussion

Individually-Managed Ponds

Basic Solution to Meet Household Nutritional Requirements

Table 3 presents the linear programming results. When all enterprise options identified on Rwandan fish farms were included in the model, along with the protein and energy levels recommended for an adequate diet, there was no feasible solution to address household nutritional requirements. The average land holding of 0.04 ha for individual farmers was too low to meet the minimum nutritional needs of a family, much less generate

Table 2. Crop yield and nutritional production for marais agricultural enterprises, Rwanda, 1995. Coop.: Cooperative respondent; Ind.: Independent respondent; $1 U.S. = 145 Rwandan francs.

Crop	Yield		Energy		Protein	
	Coop. (kg/ha)	*Ind.* (kg/ha)	*Coop.* (kg/ha)	*Ind.* (kg/ha)	*Coop.* (kg/ha)	*Ind.* (kg/ha)
Fish[1]	1,300	1,370	1,235	1,302	232	247
Sweet Potato	12,940	14,710	13,975	15,887	246	280
Irish Potato	8,500	14,020	4,879	8,048	102	168
Cassava	5,400	5,800	5,524	5,933	27	29
Taro	5,700	6,400	4,497	5,050	80	90
Sorghum	2,700	1,800	8,200	5,467	192	128
Maize	4,700	3,700	15,158	11,932	400	314
Sweet Pea	-	500	-	1,560	-	102
Beans	3,400	2,300	10,305	6,972	666	451
Soybean	2,650	1,920	9,726	7,046	824	597
Peanuts	-	1,640	-	4,559	-	192
Rice	-	5,300	-	10,971	-	212
Cabbage	11,900	15,600	2,737	3,588	178	234

[1] An additional 2.8 kg/ha and 3 kg/ha of fingerlings were produced in cooperatively- and individually-managed farms, respectively.

income. The land allocation issue will need to be addressed on a political level to allow for development of economically viable production alternatives that meet household nutritional needs.

This result was not unexpected. In some regions, caloric and proteinic deficiencies in the daily diet may occur in as much as 82% and 85% of the population, respectively (World Bank, 1989). The results of this analysis support estimates of the extent of malnutrition in Rwanda which is linked to a combination of the small land holdings and the low crop yields on subsistence holdings.

The survey data indicated that average total land holdings were 0.04 ha with a range from 0.01 to 0.16 ha. At a land allocation of 0.11 ha, without an energy constraint, the protein requirement could be met by producing 0.10 ha of soybeans. An additional 0.01 ha would be used to produce cabbage for sale to generate income. Without a protein constraint, all 0.11 ha would be used for sweet potato production, even though 0.11 ha would not produce the energy required for a family. With both protein and energy constraints included, 0.04 ha were allocated to sweet potato production and 0.07 ha to soybean production; however, nutritional requirements were not met under this production regime. Without any nutritional constraints, the 0.11 ha were allocated to cabbage production for a net farm income of Rwandan francs 28,259 (RWF) (1 U.S. $ = RWF 145). All 0.11 ha scenarios that included nutritional requirements, generated negative net farm income.

Approximately 0.20 ha of land were required in order to completely meet all nutritional requirements. Net farm income was RWF 5,198. Increased land holdings from 0.20 to 0.50 ha increased net farm income from RWF 5,198 to RWF 76,622. As land area was increased to 0.50 ha, both cabbage and peanuts were raised as cash crops.

Risk Analysis

At low levels of willingness to incur risk, the optimal product mix involved the selection of crops with low variability in yield, and those cash crop options with low coefficients of market risk. These crops were soybeans and sweet potatoes to meet household nutritional requirements and fish as the main cash crop. Even without fingerling sales, fish were selected over cabbage as the optimal cash crop. Fish have a lower variation in market price and fewer constraints compared with cabbage. At higher levels of willingness to incur risk, cabbage was selected as the optimal cash crop if fingerlings could not be sold.

Table 3. Basic results of linear programming analysis of optimal resource allocation on individually-owned subsistence farms, where all nutritional requirements are met by 0.20 and 0.50 ha of land, Rwanda, 1995.

Scenarios	Crop	Land (ha)	Crop Use	Net Income (RWF)
WITHOUT FINGERLINGS				
0.11 ha	unfeasible			
0.20 ha	sweet potato	0.08	consumption	5,198
	soybeans	0.07	consumption	
	cabbage	0.04	sale	
0.50 ha	sweet potato	0.08	consumption	72,622
	soybeans	0.07	consumption	
	cabbage	0.13	sale	
	peanuts	0.22	sale	
WITH FINGERLINGS				
0.11 ha				
All Nutritional Requirements	sweet potato	0.04	consumption	-4,444
	soybeans	0.07	consumption	
Protein Requirements	fish - large	0.006	sale	-1,855
	fingerlings	0.001	sale	
	soybeans	0.102	consumption	
Energy Requirements	sweet potatoes	0.11	consumption	-4,268
No Requirements	fish - large	0.09	sale	33,780
	fingerlings	0.02	sale	
0.20 ha	fish - large	0.037	sale	7,427
	fingerlings	0.007	sale	
	sweet potato	0.08	consumption	
	soybeans	0.07	consumption	
0.50 ha	fish - large	0.009	sale	73,648
	fingerlings	0.002	sale	
	sweet potatoes	0.082	consumption	
	peanuts	0.123	sale	
	cabbage	0.210	sale	

Cooperatively-Managed Ponds

Basic Solution to Meet Nutritional Requirements

Table 4 presents results of the models of cooperatively-managed ponds both with and without fingerling sales. Results followed trends similar to those of individually-managed ponds.

The average land holding of cooperatively-managed ponds was 0.51 ha with an average number of 13 cooperative members. This area was too small to produce enough nutrition for an average-sized cooperative whose membership consisted of families of average size. To fully meet nutritional requirements, land holdings of 2.00 ha would be required. Land holdings of cooperatives ranged from 0.01 ha to 6.03 ha, and the number of members ranged from 2 to 54.

Under a scenario which excluded fingerling production, limited available land area to 0.51 ha, and required meeting of all nutritional needs, the model selected the production of 0.21 ha maize and 0.30 ha soybean for home consumption. Considering only the need to meet protein requirements, all 0.51 ha were placed into soybean production for home consumption. When only energy requirements were considered, the model selected 0.51 ha of maize production. None of the model results for scenarios requiring the meeting of nutritional needs were profitable. Without factoring in any

Table 4. Results of linear programming analysis of cooperatively-managed subsistence farms in Rwanda, 1994 (1 U.S. $ = RWF 145).

Option	Crops	Land (ha)	Crop Use	Income (RWF)
WITHOUT FINGERLINGS				
0.51 ha				
All Nutritional Requirements	maize	0.21	consumption	-28,641
	soybeans	0.30	consumption	
Protein Requirements	unfeasible			
Energy Requirements	unfeasible			
No Nutritional Requirements	cabbage	0.51	sale	99,501
2.00 ha				
All Nutritional Requirements	maize	1.28	consumption	-10,349
	cabbage	0.30	sale	
2.50 ha				
All Nutritional Requirements	maize	1.38	consumption	8,670
	soybeans	0.30	consumption	
	cabbage	0.43	sale	
WITH FINGERLINGS				
0.51 ha	soybeans	0.21	consumption	-28,641
All Nutritional Requirements	unfeasible			
Protein Requirements	unfeasible			
Energy Requirements	unfeasible			
No Nutritional Requirements	fish - large	0.41	sale	142,600
	fingerlings	0.10	sale	
2.00 ha	fish - large	0.26	sale	12,321
All Nutritional Requirements	fingerlings	0.06	sale	
	soybeans	0.30	consumption	
	maize	1.38	consumption	

nutritional constraints, the model selected cabbage as the profit-maximizing crop and without fingerlings. Cabbage marketed without fingerlings generated a net income of RWF 99,501.

When land holdings were increased to 2.00 ha, additional land areas were allocated to cabbage production to generate income as family nutritional requirements had been met. Net farm income was still negative at 2.00 ha, but became positive at holdings of 2.50 ha and above. The maximum land holdings of cooperatively-managed ponds was 6.01 ha. It is clear that there are some cooperatives with adequate land to meet the nutritional requirements of member families and still generate cash income.

Risk Analysis

At low levels of willingness to incur risk, the optimal product mix continued to be soybeans and maize to meet household nutritional requirements, and fish production served as the primary cash crop. For individually-managed farms, as levels of willingness to incur risk increased, cabbage was selected as the profit-maximizing cash crop if there was no market for fingerlings.

Discussion

The original model specified that household nutritional requirements need to be satisfied with the mix of farm products produced. Given this specification, when risk factors were introduced into the model, there was little change in the optimal product mix. When the nutritional specifications were dropped from the model, risk factors then dictated more stable, albeit lower yielding, subsistence crops already under production by most Rwandan farmers. Thus, the need to provide for household food security dictates the use of the commonly-raised subsistence crops as the risk management strategy of choice for Rwandan farmers. Explicit estimation of risk parameters in the model generated results that were equivalent to model results which specified the achievement of household nutritional requirements. Both approaches demonstrated the rationality of subsistence farmers' selection of crops with stable, although lower, yields to maximize food security.

Acknowledgments

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Literature Cited

Belsare, D.K., 1986. Tropical Fish Farming. Environmental Publications, Karad, India.

Brooke, A., D. Kendrick, and A. Meerhuis, 1992. General Algebraic Modelling System (GAMS): Release 2.25. The Scientific Press, San Francisco, CA.

Clay, D., 1993. Prix de produits agricoles au Rwanda. Service des Enquêtes et des Statistiques Agricoles. Ministère de l'Agriculture, de l'Elevage, et des Forêts, Kigali, Rwanda.

Engle, C.R., M. Brewster, and F. Hitayezu, 1993. An economic analysis of fish production in a subsistence agricultural economy: The case of Rwanda. Journal of Aquaculture in the Tropics, 8:151-165.

Hazell, P.B.R., 1971. A linear alternative to quadratic and semivariance programming for farm planning under uncertainty. American Journal of Agricultural Economics, 53:53-62.

Hazell, P.B.R. and R.D. Norton, 1986. Mathematical programming for economic analysis in agriculture. Macmillan Publishing Co., New York.

Hishamunda, N., 1993. Economic analysis of small-scale fish culture in Rwanda: A comparative study. M.S. thesis, Auburn University, Alabama, USA.

Hishamunda, N., M. Thomas, D. Brown, and C. Engle, In Press. Small-scale fish farming in Rwanda: Economic characteristics. Technical Report. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA.

ISNAR, 1992. Report to the Government of the Republic of Rwanda. International Service for National Agriculture Research, The Hague, Netherlands.

Ministère de l'Agriculture, de l'Elevage et des Forêts, 1989. Rapport annuel, Project Pisciculture Nationale. Ministère de l'Agriculture, de l'Elevage et des Forêts, Kigembe, Rwanda.

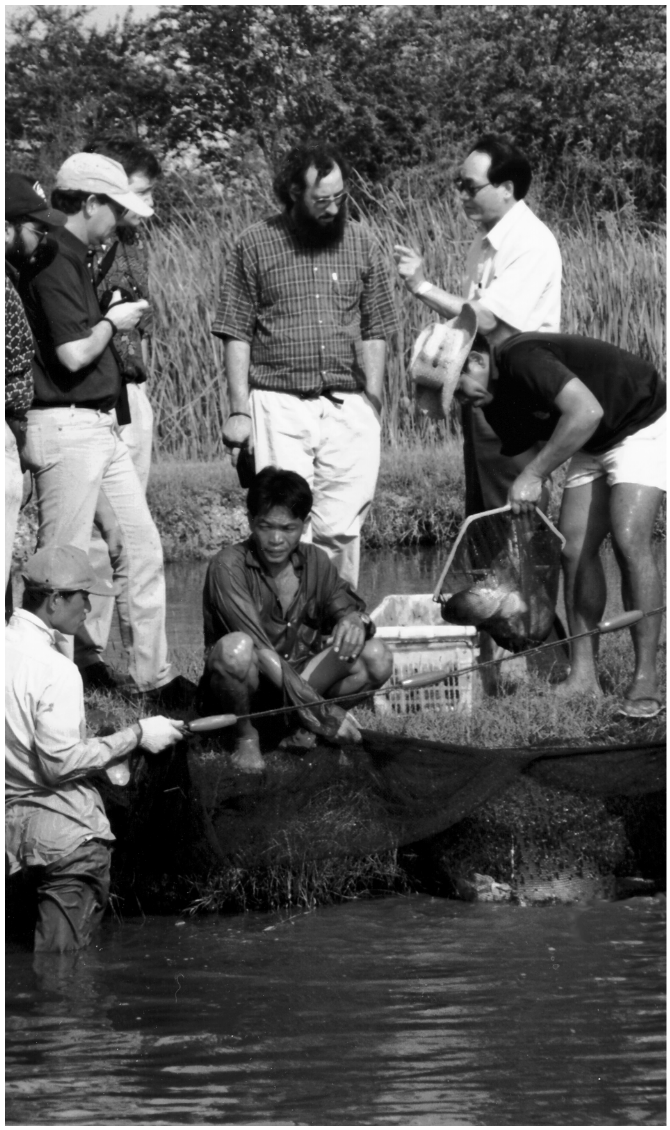
Moehl, J.F., 1993. Aquaculture development in Rwanda: A case study of resources, institutions, and technology. Ph.D dissertation, Auburn University, Alabama, USA.

Molnar, J.J., A. Rubagumya, and V. Adjavon, 1991. Sustainability of aquaculture as a farm enterprise in Rwanda. Journal of Applied Aquaculture, 1(2):37-62.

Tauer, L.W., 1983. Target MOTAD. American Journal of Agricultural Economics, 65:606-610.

Watts, M.J., L.H. Held, and G.A. Helmers, 1984. A comparison of target MOTAD to MOTAD. Canadian Journal of Agricultural Economics, 32:175-186.

World Bank, 1989. Rwanda agricultural strategy review. Report No. 4635-RW. The World Bank, New York.



Staff at the Ayutthaya Freshwater Fisheries Station in Thailand sample tilapia as other CRSP participants watch on.

Southeast Asia

Increasing the carrying capacity of ponds or harvest size of tilapia requires more intensive management practices, which largely involves supplemental feeding. The addition of supplemental feeds increases growth rates of fish stocked at higher densities; however, feeding and density increases are constrained by increased oxygen demand, build up of metabolites, or other factors which result in poor water quality. PD/A CRSP researchers from the Asian Institute of Technology (AIT) and the University of Michigan designed an experiment to test the upper limits of tilapia production utilizing supplemental feeds. Stocking densities of 3, 6, and 9 fish per m^2 were tested. While the most rapid growth and the highest survival occurred at a stocking density of 3 fish per m^2, and even though water quality remained relatively high with intensive feeding at the highest stocking density, the optimal feeding system appeared to be at a stocking density of 6 fish per m^2, particularly if the fish had been allowed to reach 500 g in size. This regime resulted in a profit of $150 per pond.

In terrestrial agriculture, analyses of extracts from soil samples are commonly used to estimate nutrient availability because the amounts of nutrients in these extracts are correlated with concentrations of nutrients in soil solution that are available to plants. It may be possible to perform similar analyses regarding the availability of nutrients in aquaculture ponds from bottom soil properties. Auburn University researchers conducted a study using laboratory soil-water microcosms under controlled conditions to determine if aqueous concentrations of substances could be predicted from soil characteristics. Data suggested that soil analyses can indicate the concentrations of water quality variables that will occur in ponds built on particular soils. Additionally, it was found that soil extractions in the dilute-acid solution provided better estimates of nutrient concentration than neutral, ammonium acetate extraction. However, further research that compares water quality in ponds with bottom soils of different physical and chemical characteristics is needed. Studies within this area could: lead to the development of more precise methods for estimating water quality and productivity from soil characteristics; allow for better use of existing soil survey data in planning aquaculture projects; and be used as a basis for recommending nutrient management programs for ponds in a given area.

Program researchers at AIT designed an experiment to develop an integrated rotation culture system for tilapia. The purpose of the experiment was to determine the effects of stocking densities of small tilapia in open ponds on the growth performance of both caged and open-pond tilapia. The growth performance of both large and small tilapia from the integrated culture system was compared with growth performance of tilapia from a mixed-pond culture system. All measures of growth performance were significantly better in the integrated culture system than the mixed-pond culture system at the same stocking density. The experiment successfully demonstrated the practicality of the cage-tilapia-cum-pond-tilapia integrated rotation system based on the intensive culture of adult Nile tilapia in cages and the semi-intensive culture of small Nile tilapia in the open water of earthen ponds. One of the major advantages of the integrated culture system is the option of controlling unwanted recruitment. Furthermore, less working capital is needed for the integrated culture system than for other intensive culture systems, since tilapia are harvested and marketed every three months. More frequent marketing may allow producers to receive better prices. The integrated culture system may be appropriate for small-scale farmers in countries such as Thailand, where large tilapia (> 500 g) receive a much higher market price than those typically harvested in fertilized ponds, which weigh between 250 and 300 g.

PD/A CRSP researchers from AIT and the University of Michigan assessed the effects of carp-tilapia polyculture on water quality and fish yield in deep, rain-fed ponds. Water temperatures and dissolved oxygen (DO) concentrations of surface water and water at the bottom of ponds for monthly data were not significantly different among treatments. DO values were most variable, and mean total Kjeldhal nitrogen and chlorophyll-*a* concentrations in all treatments showed an increase toward the end of the culture periods. Experimental results did not reveal any differences between net fish yields from the Nile tilapia monoculture and the polyculture of Nile tilapia with common carp at different densities. Common carp lost weight during the experimental period in polycultured ponds, which may have been due to the undesirable feeding habitat available to the carp in deep ponds. The accumulation of organic matter in the bottom of deep ponds can lead to an oxygen deficit condition and the production of reduced substances, such as nitrite, ammonia, hydrogen sulfide, and methane, which are toxic to benthic organisms.

Carp/tilapia polyculture may be more difficult in ponds constructed on acid sulfate soils because carp tend to stir sediment as part of their feeding activities. This may result in reduced alkalinity as well as in the suspension of aluminum or iron, which in turn could affect phosphorus availability. Researchers from the University of Hawaii and AIT therefore conducted an experiment to determine the effect of carp/tilapia polyculture on fish production, nutrient dynamics, turbidity, and primary productivity. Tilapia growth was slow and uniform across treatments. Carp growth was extremely sensitive and inversely related to stocking density. There were only slight indications of treatment-related differences in water quality, except for measures of turbidity. Biomass rather than individual fish size increased suspended solids. Chlorophyll-*a* levels were not high; however, they were sufficient to improve tilapia growth.

Data from the CRSP Central Database were analyzed by researchers from the University of Hawaii to determine the relationship between primary productivity and fish production. Primary productivity/fish yield relationships were compared with the results of PONDCLASS trials in Thailand and the Philippines. Most ponds produced 2 to 8 mg/l DO during the daytime. Daytime DO production and fish yield were related with high statistical significance.

Stocking Density and Supplemental Feeding

Work Plan 6, Thailand Study 6

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Introduction

Pond carrying capacity is largely determined by management practices. Earlier work on semi-intensive culture of tilapia using manure or inorganic fertilizers indicated that carrying capacity might reach 2,000 to 3,000 kg/ha (Diana et al., 1991a and 1991b; Knud-Hansen et al., 1991). As stocking density increases in fertilized ponds, carrying capacity remains largely the same and density-dependent growth occurs (Diana et al., 1991b). Thus the ultimate size of fish at harvest is largely related to the density stocked in fertilized ponds, while biomass at harvest is more consistent regardless of stocking density. Maximum size at harvest for these fertilized ponds is approximately 250 g for fish grown five months.

Increasing the carrying capacity or size at harvest of tilapia requires more intensive management, which largely involves supplemental feeding. Experiments with supplemental feeding indicated that tilapia can reach 500 g in 5 months when feed and fertilizers are provided in combination (Diana et al., 1994, in press). Such experiments were done at fish densities of 3 fish/m^2, which would cause density-related declines in growth for fish in fertilized ponds. However, the addition of supplemental feed increased the growth rate of fish stocked at high density, and resulted in a higher carrying capacity for the pond. The limit on such feeding and density increases is reached when conditions in ponds climb to limiting levels due to increased oxygen demand, build up of metabolites, or other factors which produce poor water quality. Such a limit to tilapia production was demonstrated for Honduran ponds stocked at 3 fish/m^2 (Green, 1992) while Diana et al. (1994) found no decline in water quality for tilapia stocked at 3 fish/m^2 in Thai ponds. In the latter study, concomitant fertilization probably helped maintain reasonable water quality.

The purpose of this experiment was to determine the upper limits to tilapia production utilizing supplemental feeds. In order to test this relationship, fish were stocked at three, six, and nine fish/m^2. These fish were supplementally fed to 50% satiation for 191 days. This manuscript represents the third run of this study. Pond poaching biased the first attempt. The second attempt gave reasonable results, except that water quality differences were insignificant among treatments. This attempt used automated monitoring of dissolved oxygen.

Materials and Methods

Data for this study were collected at the Ayutthaya Freshwater Fisheries Station located at Bang Sai (140° 45' N, 100° 32' E), approximately 60 km northwest of Bangkok, Thailand. The nine ponds used in the experiment were 280 m^2 in surface area and normally filled to a depth of 1 m. Sex-reversed

Table 1. The biomass (kg), number, and mean size (g) of tilapia stocked and harvested in each experimental pond.

Pond	Stocking			Harvest		
	Number	*Biomass (kg)*	*Size (g)*	*Number*	*Biomass (kg)*	*Size (g)*
A1	840	12.8	15.2	678	335.2	494
A2	840	12.8	15.2	735	445.1	606
A3	840	12.2	14.5	669	313.9	469
B1	1680	26.3	15.6	1155	502.5	435
B2	1680	26.6	15.8	1357	652.8	481
B3	1680	26.4	15.7	1351	567.6	420
C1	2520	38.1	15.1	1325	417.4	315
C2	2520	40.3	16.0	1382	452.5	327
C3	2520	41.1	16.3	1634	533.5	326

Nile tilapia (*Oreochromis niloticus*) averaging 15 g were stocked on 28 July 1995 (Table 1). The ponds were divided randomly into three treatments, with triplicate ponds for each treatment receiving either three, six, or nine fish per m^2 (840, 1680, and 2520 fish per pond). Fish were fed to satiation from 0800-1000 h and 1500-1700 h every Monday. Maximum consumption was determined using floating feed (30% crude protein) and was estimated individually for each pond. The average consumption for each treatment was used to set the feeding rate at 50% of that level for the remainder of the week.

In addition to feeding, ponds were also fertilized weekly to bring a balance of N and P addition to 4 and 1 kg/ha/d, respectively. Fertilization was done to balance input of N and P generated in fish wastes. The amounts of N and P in fish wastes were estimated weekly from total feed inputs and fish biomass, based on N and P contents of feed and fish carcasses (feed = 10% moisture, 4.2% N, and 1.2% P; fish = 78% moisture, 2.2% N, and 0.6% P). Urea and triple super phosphate (TSP) were used for this balancing, with average daily inputs of 4.1 kg urea/ha and 4.5 kg tsp/ha.

Physical and chemical data were collected in a similar manner to earlier experiments (Diana et al., 1991a and 1994). Meteorological data, including solar radiation, rainfall, and wind speed were collected daily. For most analyses, a combined water sample encompassing the entire water column was taken from three locations of each pond. Pond water analyses, including temperature, dissolved oxygen (both taken at the top, middle, and bottom of the water column), ammonia, nitrate-nitrite, orthophosphate, total phosphorus, alkalinity, pH, Secchi-disk depth, and chlorophyll-*a* content were conducted biweekly using standard methods (see APHA, 1980 and Egna et al., 1987, for detailed descriptions of methods). Finally, dissolved oxygen concentrations were evaluated regularly by data loggers for two ponds in each treatment. Readings were taken near the surface (25 cm below) and bottom (25 cm above) of each pond at hourly intervals most days (121 out of 194 days) of the experimental period.

Ponds were harvested on 7 February 1996, after 194 days. Final biomass and numbers were determined. Overall individual growth (g/d) and net yield (kg) were calculated. During the experiment, fish were sampled biweekly for size. About 40 fish were seined from each pond, measured, and weighed. Biomass in the pond was estimated biweekly by extrapolating the number of fish in the pond linearly from stocking to harvest and multiplying this number by the average size of fish.

Preliminary economic evaluations of each growout were done using POND© 3.0 (Bolte et al., 1996). Facility costs and labor were not included. Local market prices were used for income and expenses. Feed prices were set at $0.50 per kg, fertilizer (urea and TSP) at $0.28 per kg, and sex-reversed fry at $0.009 each. Market value of Nile tilapia varied with size: fish from 300-500 g sold at $0.60 per kg, while fish above 500 kg sold at $0.80 per kg.

Statistical analyses were conducted using SYSTAT (Wilkinson, 1990). Overall growth (g/day), net yield (kg), and percent survival were calculated for each pond. Feeding rate (% BW/d) was estimated

Table 2. Growth (g/fish/d), survival (%), yield (kg), feed applied (kg), feed conversion rate (FCR), and forecasted annual yield (kg/ha/yr) for tilapia from each pond.

Pond	Growth	Survival	Yield	Feed	FCR	Annual Yield
A1	2.47	80.7	322	463	1.44	21663
A2	3.04	87.5	432	505	1.17	29048
A3	2.34	79.6	302	458	1.52	20273
B1	2.16	68.8	476	624	1.31	32001
B2	2.40	80.8	626	783	1.25	42080
B3	2.08	80.4	541	712	1.32	36369
C1	1.55	52.6	379	590	1.55	25490
C2	1.61	54.8	412	660	1.60	27701
C3	1.60	64.8	492	689	1.40	33090

biweekly, while feed conversion rate (FCR) was calculated for overall data and for biweekly data. Average overall values for physical and chemical parameters and total food input were also calculated. Multiple regressions between growth and density were done to test main effects. Because many of the chemical variables were interrelated, residuals of the above regression were correlated to each physical or chemical variable. Variables which were significantly correlated to the residuals were then examined for autocorrelation, and acceptable variables were used as input for multiple regression to evaluate additional determinants of variations in fish growth, survival, or yield. Variables were included in the regression if $p < 0.10$. Treatment effects on fish or chemical variables were tested with the biweekly data set by ANOVA and Tukey's multiple range test. Differences were considered significant at an alpha of 0.05.

Results

Fish growth rate proceeded in a linear fashion throughout the experiment (Figure 1). Overall growth rate differed significantly among treatments (ANOVA, $p < 0.05$) with the low and intermediate density treatments having higher growth than the high density treatment but not being significantly different from one another (Tukey's test, $p < 0.05$; Table 2). Similarly, survival

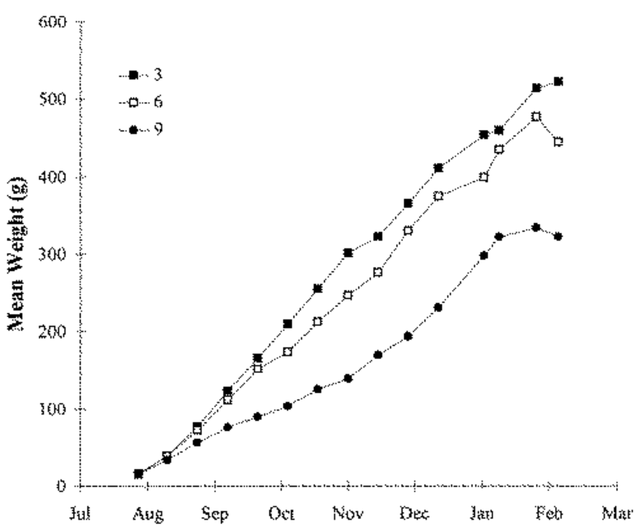

Figure 1. Changes in mean weight of tilapia during culture under three treatments.

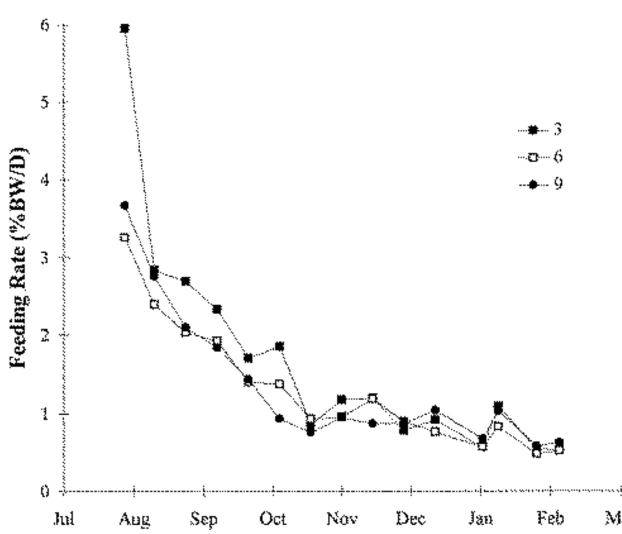

Figure 2. Changes in feeding rate and feed conversion rate during culture for ponds in each treatment.

Table 3. Multiple regression results for main effects (density) related to fish growth (g/d), survival (%), and yield (kg).

Variable	Coefficient	P
GROWTH RATE ($r^2 = 0.789$, $p < 0.001$)		
Constant	3.169	0.001
Density	-0.172	0.001
SURVIVAL ($r^2 = 0.736$, $p < 0.001$)		
Constant	0.978	0.001
Density	-0.042	0.002
YIELD ($r^2 = 0.000$, $p > 0.05$)		
Constant	366.78	0.006
Density	12.61	0.408

was varied among treatments, with lowest survival in the high density treatment but with no significant differences between the two lower density treatments (Tukey's test, $p < 0.05$; Table 2).

Feeding rate was initially high but then declined in all treatments (Figure 2). Feeding rate did not differ significantly among treatments (mean = 1.65% BW/d). Feed conversion rate averaged 1.40 and did not differ significantly among treatments.

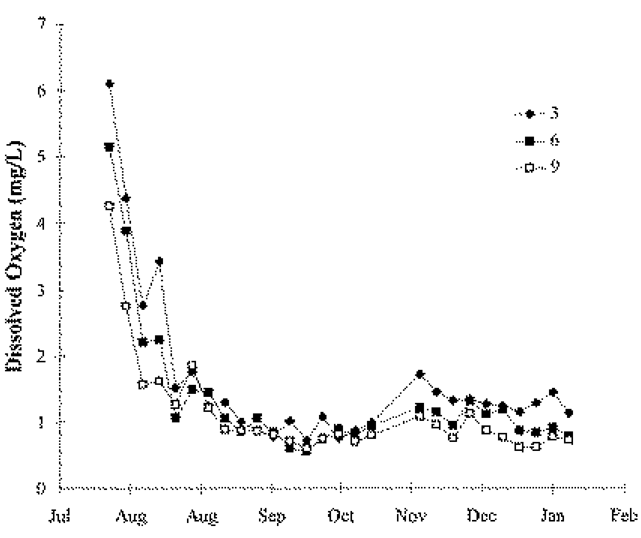

Figure 3. Changes in dissolved oxygen content of pond water during culture in each treatment.

Most physical and chemical variables showed no significant differences among treatments. Exceptions were alkalinity, which was significantly different in all three treatments, as well as NH_3 and dissolved inorganic nitrogen (DIN), which were significantly higher in the high density treatment than in the other two treatments (Tukey's test, $p < 0.05$). Alkalinity was highest in the mid density treatment (224 mg/l), intermediate in the low density treatment (169), and lowest in the high density treatment (141 mg/l).

Dissolved oxygen levels were difficult to analyze due to the large volume of data produced. Mean DO at 0600 h was significantly different among treatments (Tukey's test, $p < 0.05$), with low and mid density treatments having similar levels (1.58 and 1.31 mg/l, respectively), while mid and high density also had similar levels (1.31 and 1.08 mg/l, respectively; Figure 3). There were significant differences in the total number of data-logged hours when DO was less than 1 mg/l; mean values were similar at low and mid densities (167 and 353, respectively) and at mid and high densities (353 and 550, respectively).

Growth rate was significantly correlated to density ($r^2 = 0.789$, $p < 0.001$; Table 3). Residuals of this regression were not significantly correlated to any chemical or physical variables. Survival was also significantly related to density ($r^2 = 0.736$, $p < 0.01$).

Table 4. Calculation of profit for each stocking density.

Treatment Density (fish/m^2)	Fertilizer (kg)	Feed (kg)	Biomass at Harvest (kg)	Fish Size (g)	Profit per Pond
3	46.3	475	352	523	$23.40
6	43.7	520	547	445	$40.67
9	51.3	646	427	322	$-104.05

Residuals of this regression were also not significantly correlated to any physical or chemical variable. Finally, yield was not significantly related to density ($p > 0.05$).

Alkalinity and DIN differed among treatments (Figure 4). Both were also significantly correlated to one another using overall data (Figure 5) but not with biweekly data. This relationship is difficult to understand.

The economic analysis indicated that the growouts at 3 and 6 fish/m^2 were profitable (Table 4). Fish at 6 fish /m^2 did not reach 500 g at harvest, which would produce a higher market price. If price per kg of fish were the same ($.80) for each treatment, then the treatment at 6 fish/m^2 would be even more profitable ($150 per pond).

Discussion

Growth and survival of tilapia differed as expected among treatments, with best growth and survival at lowest density. Trends in growth rate among treatments were clearly differentiated by the first month sample. Growth was rapid in all ponds and reached rates near the maximum measured for tilapia cultured in ponds although growth was slightly lower than in our previous density experiment (Diana et al., 1995). Reductions in growth which occurred at high density appeared to be due to poor water quality because dissolved oxygen concentration at dawn (total hours when DO was less than one) and NH_3 levels all differed significantly among treatments.

Under normal conditions, profit was generated by fish grown at 6 fish/m^2 maximum ($40.67 per pond). However, if fish in the 6 fish/m^2 treatment had reached 500 g in size, they would have generated even more income ($148.00 per pond). Return rates in the current experiment were comparable to our earlier experiments (Diana et al., 1996); however, extrapolated profit for 6 fish/m^2 and 500 g final weight would have been the best for all our treatments to date.

Most rapid growth and highest survival occurred at 3 fish/m^2. The optimal feeding system at present

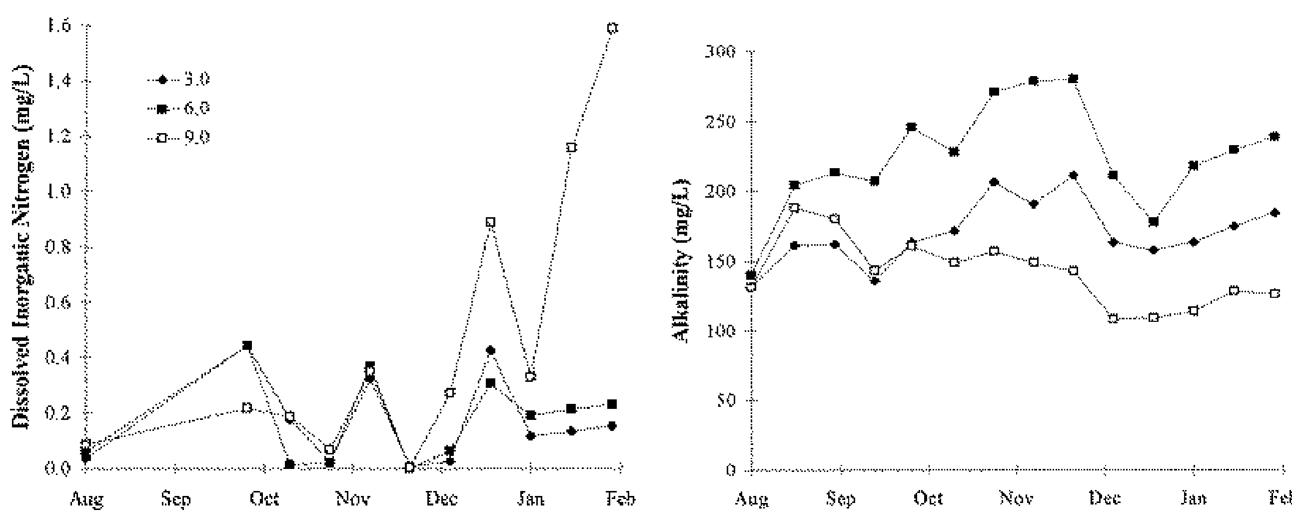

Figure 4. Changes in dissolved inorganic nitrogen and alkalinity during culture in each treatment.

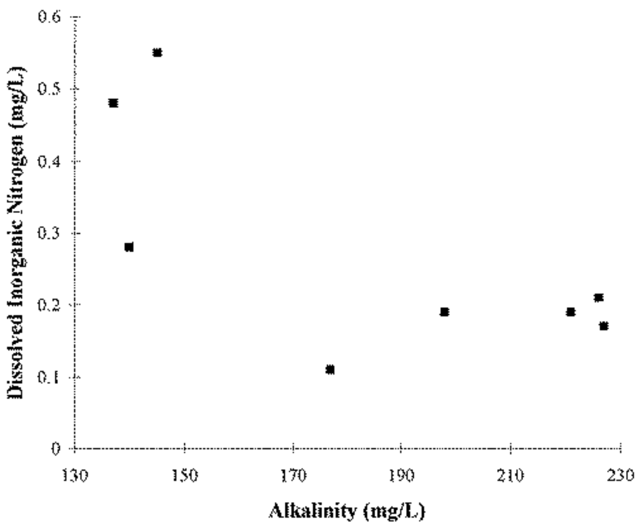

Figure 5. Relationship between alkalinity and dissolved inorganic nitrogen in ponds of all treatments.

appears to be with tilapia stocked at 6 fish/m^2. The combined application of feed and fertilizer remains an important tool because even at 9 fish/m^2 and intensive feeding, water quality remained relatively high. The fertilizer/fish waste balancing of inputs in this experiment appeared to be a successful way to control nutrient addition, as there were no differences in most chemical and biological variables between treatments. In our previous density experiment, chlorophyll-*a* content was higher in high density ponds, apparently in response to increased P levels, which were correlated to feed input rate (Diana et al., 1995). The same relationships occurred in this experiment.

Literature Cited

American Public Health Association (APHA), 1980. Standard Methods for the Examination of Water and Wastewater, 15th Edition. American Public Health Association Washington, D.C. 1134 pp.

Bolte, J., S. Nath, and D. Ernst, 1996. POND Version 3.0. Department of Bioresource Engineering, Oregon State Unversity, Corvallis, USA.

Diana, J.S., D.D. Dettweiler, and C.K. Lin, 1991a. Effect of Nile tilapia (*Oreochromis niloticus*) on the ecosystem of aquaculture ponds, and its significance to the trophic cascade hypothesis. Canadian Journal of Fisheries and Aquatic Sciences, 48:183-190.

Diana, J.S., C.K. Lin, and P.J. Schneeberger, 1991b. Relationships among nutrient inputs, water nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. Aquaculture, 92:323-341.

Diana, J.S., C.K. Lin, and K. Jaiyen, 1994. Supplemental feeding of tilapia in fertilized ponds. Journal of the World Aquaculture Society, 25:497-506.

Diana, J.S., C. K. Lin, and Y. Yi, 1995. Stocking density and supplemental feeding. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair, (Editors), Thirteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 117-125.

Diana, J.S., C.K. Lin, and Y. Yi, in press. Timing of supplemental feeding for tilapia production. Journal of the World Aquaculture Society.

Egna, H.S., N. Brown, and M. Leslie, 1987. Pond Dynamics/Aquaculture Collaborative Research Data Reports, Volume 1: General Reference: Site Descriptions, Material and Methods for the Global Experiment. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, 84 pp.

Green, B.W., 1992. Substitution of organic manure for pelleted feed in tilapia production. Aquaculture, 101:213-222.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson, 1991. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. Proceedings of the International Association of Theoretical and Applied Limnologists, 24:2541-2543.

Wilkinson, L., 1990. SYSTAT: The System for Statistics (manual and 5 diskettes). SYSTAT, Inc., Evanston, Illinois, 677 pp.

Water Quality in Laboratory Soil-Water Microcosms with Soils from Different Areas of Thailand

Interim Work Plan, Africa Study 5

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Introduction

Interpretations of soil analyses for use in aquaculture endeavors are difficult because few data are available on relationships between soil chemical and physical properties and aqueous concentrations of water quality variables or between soil properties and aquatic animal production (Boyd, 1995). Banerjea (1967) related selected soil properties to fish production in ponds in India. He identified optimum ranges of soil carbon, nitrogen, phosphorus, and pH for fish production in fertilized ponds. However, he did not consider the influence of bottom soil characteristics on water quality in ponds. Several authors have demonstrated that edaphic factors influence the chemical composition of pond waters (Moyle, 1956; Boyd and Walley, 1975; Arce and Boyd, 1980), but equations for predicting water quality from soil characteristics were not provided. Boyd (1974) developed a method for determining the lime requirement of ponds based upon bottom soil analysis. Boyd et al. (1994) presented a large array of data on chemical characteristics of freshwater and brackish water pond soils and assigned concentration categories as very low, low, medium, high, and very high. However, no attempt was made to relate the soil characteristics to water quality or production in ponds. A recent study by Boyd and Munsiri (1996) indicated that the phosphorus status of pond soils for aquaculture could be assessed from phosphorus adsorption capacity and clay content.

In terrestrial agriculture, analyses of extracts from soil samples are commonly used to estimate nutrient availability, because the amounts of nutrients in these extracts are correlated with concentrations of nutrients in soil solution that are available to plants (Walsh and Beaton, 1973; Brady, 1990). Soil nutrient extractions are the basis for soil testing methods to determine fertilizer requirements for crops at specific locations. It may be possible to predict the availability of nutrients in aquaculture ponds from bottom soil properties. The main obstacle to research on relationships among pond soil characteristics, water quality, and aquatic animal production is locating experimental ponds on soils of different physical and chemical characteristics. In terrestrial agriculture, greenhouse studies with small pots of soil as experimental units have been widely used in evaluating relationships between soil properties and plant growth (Rouse, 1968; Walsh and Beaton, 1973). Therefore, a study was conducted using laboratory soil-water microcosms under controlled conditions to determine if aqueous concentrations of substances could be predicted from soil characteristics.

Materials and Methods

Forty-five soil samples were collected from 23 provinces in central, eastern, and northern Thailand in September 1994. Twenty of the samples were used earlier in a study of the phosphorus adsorption capacity of soils from Thailand (Boyd and Munsiri, 1996). The other 25 samples were from areas nearby those indicated on a map provided by Boyd and Munsiri (1996), so further identification of sampling site locations will not be provided. Samples included the following soil orders: Alfisols, Entisols, Inceptisols, Mollisols, Ultisols, and Vertisols. This array of samples was quite diverse and included at least 14 soil suborders and about 40 soil series, but it was not possible to classify all samples to taxonomic levels below order with certainty. Samples were collected from areas near fish ponds but not from bottoms of existing ponds. Soils were similar to those used for pond construction at the sampling sites, and they were considered representative of soils in the bottoms of newly-constructed ponds. Most sites had not been used for agriculture in the past, but we think that agricultural crops may have been cultivated on 8 or 10 of the sites within the past few years. Samples were collected from the 15-30 cm depth layer, and about 200-g quantities of each were placed in plastic bags for transport to Auburn, Alabama.

Samples were dried at 40°C in a forced-draft oven. Nutrients were extracted from soils by two solutions (a mixture of 0.05 N HCl plus 0.025 N H_2SO_4 and neutral, 1 N ammonium acetate) and analyzed by plasma spectrophotometry (ICAP). Soil pH was determined with a glass electrode in a 1:1 soil-distilled water mixture. Sand, silt, and clay analyses were made by the pipet method (Gee and Bauder, 1986). Total carbon concentrations were measured with an induction furnace carbon analyzer (Leco Model EC 12). To determine cation exchange capacity (CEC), the exchangeable acidity was measured and added to the sum of basic exchangeable cations (calcium, magnesium, sodium, and potassium) extracted by neutral, 1 N ammonium acetate. Base saturation was estimated by dividing the sum of basic exchangeable cations by CEC. Methods for soil analyses are described in greater detail by Munsiri et al. (1995).

Soil-water microcosms were prepared in triplicate for each soil by adding 5.0 g soil and 150 ml of distilled water into a 250-ml Erlenmeyer flask. Flasks were placed on a rotating table shaker (150 rpm) at 25°C in the dark for 7 days. Water from the microcosms was filtered through a 0.45-m membrane filter. The pH was measured with a glass electrode, and total alkalinity and total hardness were measured by standard titration procedures using a microburette (APHA et al., 1989). A portion of the filtered solution was used for soluble reactive phosphorus (SRP) analysis by the ascorbic acid method (APHA et al., 1989). Another portion of the filtered solution was analyzed for metallic cations and boron by plasma spectrophotometry.

Regression analyses to evaluate relationships between soil characteristics and aqueous concentrations of dissolved substances and pH were conducted using spreadsheet software. Linear, exponential, and logarithmic regressions were evaluated for each combination of variables.

Results and Discussion

For sake of brevity, only the ranges and medians of the soil physical and chemical variables are reported (Table 1). The set of samples included a wide range of most variables but did not include samples with high concentrations of total carbon. Medians of most variables are skewed to the right of the mid-points of the ranges. Using potassium as an example, the range was 8-442 ppm. The mid-point of the range was 217 ppm, but the median was only 59 ppm. Thus, there was a greater proportion of lower values than of higher ones. Nevertheless, the upper ends of the concentration ranges were represented by several samples of differing concentration.

The microcosms were held on the rotating shaker for 7 days, but the analysis of water from some extra microcosms included in the experiment indicated that concentrations of nutrients did not increase after the second day. Thus, it is reasonable to assume that equilibrium conditions had been reached in all flasks by the seventh day. Ranges and medians of concentration of water quality variables in the microcosms also are reported in Table 1. These data are skewed to the right in the same manner as the soil analysis data.

The average concentrations of water quality variables in microcosms are presented for each soil order in Table 2. Because of the large variation within orders, none of the means differed (ANOVA; $P > 0.05$). Therefore, knowledge of soil order is of no benefit in determining the concentrations of dissolved substances or pH in water in contact with soil. No further attempt was made to correlate soil taxonomy and water quality because of the inability to designate soil classification exactly for some samples and the small sample size that was represented by some taxonomic units.

Results of regression analyses between nutrient concentrations in soil and nutrient concentrations in waters of microcosms are provided in Table 3. In all cases, the highest correlation coefficients were for linear regressions. Also, regression coefficients obtained using dilute-acid extractable nutrients as independent variables generally were greater than those achieved with neutral, 1 N ammonium acetate extractable nutrients as independent variables. The strongest correlations were obtained for sodium, potassium, phosphorus, and calcium. Soil extracts would be more useful for predicting concentrations of these nutrients than for magnesium, manganese, and boron, for which correlations were weaker.

Table 1. Ranges and medians for chemical and physical characteristics of soils used in microcosm experiments. Soil nutrients were extracted with dilute acid (DA) and with neutral ammonium acetate (AA). Ranges and medians for concentrations of dissolved substances and pH in waters of microcosms also are presented.

Variable	Range	Median
SOIL		
P		
(DA)	1.7 - 76.5	7.4 ppm
(AA)	0.0 - 5.8	0.5 ppm
Ca		
(DA)	36 - 5,415	1,495 ppm
(AA)	37 - 6,949	1,514 ppm
Mg		
(DA)	23 - 1,263	189 ppm
(AA)	27 - 2,386	253 ppm
K		
(DA)	8 - 442	59 ppm
(AA)	7 - 491	131 ppm
Na		
(DA)	18 - 2,192	64 ppm
(AA)	22 - 2,238	74 ppm
FE		
(DA)	4 - 368	32 ppm
(AA)	3 - 15	8 ppm
Mn		
(DA)	0.6 - 182	47 ppm
(AA)	0.3 - 99	9 ppm
B		
(DA)	0.1 - 4.1	0.7 ppm
(AA)	0.1 - 2.0	0.2 ppm
C	0.17 - 2.49	0.91%
BS*	0.5 - 75.0	17.6%
CEC*	1.9 - 44.7	25.6 meq/100 g
pH	3.9 - 8.2	7.1
Sand	4 - 80	28%
Silt	12 - 68	36%
Clay	7 - 67	25%

* BS = base saturation
CEC = cation exchange capacity

Variable	Range	Median
WATER IN MICROCOSMS		
P	0.1 - 0.95	0.1 mg/l
Ca	0.1 - 30.9	6.0 mg/l
Mg	0.1 - 25.0	1.1 mg/l
K	0.1 - 12.9	1.0 mg/l
Fe	0.01 - 2.90	0.25 mg/l
Mn	0.01 - 2.85	0.30 mg/l
B	0.01 - 0.25	0.11 mg/l
pH	3.8 - 8.5	6.6
TA*	0.0 - 73.8	21.8 mg/l
TH*	0.5 - 174.2	21.7 mg/l

* TA = total alkalinity
TH = total hardness

Table 2. Average concentrations and standard errors of dissolved substances and pH laboratory soil-water microcosms containing soil of different orders (n = sample size).

	Alfisols (n = 10)	**Entisols (n = 4)**	**Inceptisols (n = 8)**	**Mollisols (n = 4)**	**Ultisols (n = 16)**	**Vertisols (n = 3)**
Phosphorus	0.20 ± 0.09	0.32 ± 0.10	0.22 ± 0.07	0.15 ± 0.25	0.25 ± 0.04	0.23 ± 0.03
Calcium	10.3 ± 3.5	11.1 ± 3.0	13.0 ± 3.6	23.1 ± 4.8	4.7 ± 1.7	29.0 ± 8.3
Magnesium	1.7 ± 0.5	2.8 ± 1.7	4.8 ± 2.9	2.6 ± 0.4	0.9 ± 0.3	3.4 ± 2.7
Potassium	2.2 ± 1.2	3.7 ± 2.3	2.5 ± 0.9	1.7 ± 0.3	1.1 ± 0.6	2.2 ± 1.2
Sodium	8.5 ± 3.6	25.1 ± 21.0	11.1 ± 3.5	3.4 ± 0.6	6.6 ± 1.9	5.1 ± 2.8
Iron	0.21 ± 0.03	0.22 ± 0.06	0.25 ± 0.05	0.23 ± 0.03	0.7 ± 0.42	0.33 ± 0.17
Manganese	0.35 ± 0.14	0.31 ± 0.12	0.70 ± 0.39	0.03 ± 0.02	0.42 ± 0.21	0.81 ± 0.80
Boron	0.09 ± 0.01	0.04 ± 0.02	0.11 ± 0.02	0.02 ± 0.02	0.04 ± 0.02	0.01 ± 0.02
Total Alkalinity	25.9 ± 6.9	57.0 ± 25.4	18.7 ± 6.1	56.4 ± 8.6	14.3 ± 3.4	55.2 ± 16.7
Total Hardness	32.7 ± 10.4	39.4 ± 11.4	52.4 ± 19.5	68.3 ± 10.4	15.7 ± 5.4	86.6 ± 36.7
pH	6.7 ± 0.2	7.8 ± 0.5	5.6 ± 0.4	7.5 ± 0.1	6.3 ± 0.2	7.5 ± 0.3

Table 3. Correlation matrix for linear regressions of soil nutrient concentrations (X) versus concentrations of dissolved nutrients in laboratory soil-water microcosms (Y).[a] There are two regression coefficients for each comparison. The upper one is for soil nutrients extracted in dilute acid. The lower one in parentheses is for the soil nutrient extracted in neutral, ammonium acetate.

Soil	Water							
	P	*Ca*	*Mg*	*K*	*Na*	*Fe*	*Mn*	*B*
P	0.816 (0.095)							
Ca	0.261 (0.032)	0.685 (0.605)						
Mg	0.167 (0.045)	0.141 (0.063)	0.470 (0.401)					
K	0.683 (0.538)	0.045 (0.179)	0.205 (0.378)	0.959 (0.866)				
Na	0.109 (0.095)	0.063 (0.032)	0.307 (0.298)	0.045 (0.045)	0.977 (0.975)			
Fe	0.032 (0.077)	0.195 (0.349)	0.265 (0.395)	0.063 (0.032)	0.071 (0.521)	0.141 (0.224)		
Mn	0.032 (0.032)	0.212 (0.000)	0.366 (0.619)	0.243 (0.134)	0.438 (0.224)	0.089 (0.000)	0.462 (0.434)	
B	0.341 (0.032)	0.243 (0.077)	0.510 (0.416)	0.276 (0.063)	0.794 (0.728)	0.053 (0.130)	0.197 (0.063)	0.399 (0.303)

[a] Correlation coefficients (r) greater than 0.291 and 0.376 are significant at probability levels of 5% and 1%, respectively.

Dissolved iron concentration in microcosms was not correlated with soil iron. Few significant correlations were found between other combinations of soil nutrients and nutrients in solution. However, there was a very strong correlation between boron in soil and sodium in water. This correlation is not surprising, since sodium and boron are cyclic marine salts with similar geochemical cycles (Boyd and Walley, 1972).

Correlations among other soil properties and pH, nutrient concentrations, total alkalinity, and total hardness are provided in Table 4. Correlations between soil particle size classes (sand, silt, and clay) and dissolved concentrations of variables were weak or lacking. Soil pH was highly correlated with total alkalinity and pH in waters of microcosms. There were significant correlations between both CEC and base saturation of soils and several variables in microcosm waters, but the best correlations were between these two soil variables and total alkalinity. Total alkalinity also was correlated with the sum of soil calcium and magnesium extracted with either of the extracting agents. Total hardness was related to concentrations of soil calcium plus magnesium, but, surprisingly, soil carbon provided the strongest correlation with total hardness. The reason for this correlation is possibly related to soil organic matter contributing to CEC, and soils with a higher CEC tend to adsorb more calcium, magnesium, and other cations than soils of lower CEC. The correlation between CEC and total hardness was significant but not as great as the one between soil carbon and total hardness. It is possible that some of the soils with high pH contained free calcium carbonate that contributed to alkalinity.

Equations for predicting concentrations of dissolved substances and pH in microcosms are not provided because they would not be reliable for use in aquaculture ponds that are much more complex chemically, physically, and biologically than the microcosms. Nevertheless, the data suggest that soil analyses can indicate the concentrations of water quality variables that will occur in ponds built on a particular soil. It also is noteworthy that extraction of soil in the dilute-acid solution provided better estimates of nutrient concentrations than the neutral, ammonium acetate extraction. The dilute-acid solution is easier to prepare and store than the ammonia acetate solution. Although soil

Table 4. Correlation coefficients for soil properties versus pH and nutrient, total alkalinity (TA), and total hardness (TH) concentrations in waters of soil-water microcosms.[a] Regression coefficients are for linear regression except in parenthesis (exponential regression) or brackets [logarithmic regression].

Soil	Water										
	P	*Ca*	*Mg*	*K*	*Na*	*Fe*	*Mn*	*B*	*TA*	*TH*	*pH*
Carbon	0.176	0.690	0.518	0.114	0.308	0.032	0.366	0.077	0.631	0.710	0.155
Base Saturation	0.000	0.469	0.330	0.000	0.508	0.187	0.045	0.176	0.729	0.475	0.424
Cation E□xchange	0.094	0.446	0.417	0.000	0.502	0.200	0.000	0.254	0.664	0.491	0.197
pH	0.316	0.375	0.134	0.184	0.032	0.105	0.145	0.341	(0.877)	0.228	[0.937]
Sand	0.224	0.200	0.324	0.189	0.318	0.130	0.045	0.279	0.224	0.274	0.192
Silt	0.032	0.077	0.063	0.187	0.045	0.071	0.126	0.100	0.000	0.084	0.000
Clay	0.263	0.195	0.360	0.100	0.430	0.217	0.045	0.279	0.307	0.285	0.232
Calcium + Magnesium (Dilute-acid Extractable)	---	---	---	---	---	---	---	---	(0.843)	(6.35)	0.641
Calcium + Magnesium (Ammonium Acetate Extractable)	---	---	---	---	---	---	---	---	(0.753)	(0.520)	0.487

[a] Correlation coefficients (r) greater than 0.291 and 0.370 are significant at probability levels of 5% and 1%, respectively.

clay content provides a good estimate of the capacity of pond soil to adsorb phosphorus (Boyd and Munsiri, 1996), clay content was not a good predictor of nutrient concentrations in waters of the microcosms.

Findings of this study reveal the need for research to compare water quality in ponds with bottom soils of different physical and chemical characteristics. Such studies could lead to the development of more precise methods for estimating water quality and productivity from soil characteristics. These methods could be used as a basis for recommending nutrient management programs for ponds in a given area. They also would allow for better use of existing soil survey data in planning aquaculture projects. Hajek and Boyd (1994) pointed out that soil survey reports contain much useful information for site selection, design, and construction of ponds, but further use of soil survey reports is limited by lack of knowledge about soil-water interactions in ponds.

Literature Cited

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation, 1989. Standard methods for the examination of water and wastewater, 17th Edition. APHA, Washington, D.C., USA.

Arce, R.G. and C.E. Boyd, 1980. Water chemistry of Alabama ponds. Bulletin 522, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Banerjea, S.M, 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian Journal of Fisheries, 14:113-144.

Boyd, C.E., 1974. Lime requirements of Alabama fish ponds. Bulletin 459, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.E., 1995. Bottom soils, sediment, and pond aquaculture. Chapman and Hall, New York, USA.

Boyd, C.E. and P. Munsiri, 1996. Phosphorus adsorption capacity and availability of added phosphorus in soils from aquaculture areas in Thailand. Journal of the World Aquaculture Society, 27:160-167.

Boyd, C.E. and W.W. Walley, 1972. Studies of the biogeochemistry of boron. I. Concentrations in surface waters, rainfall, and aquatic plants. American Midland Naturalist, 88:1-14.

Boyd, C.E. and W.W. Walley, 1975. Total alkalinity and hardness of surface waters in Alabama and Mississippi. Bulletin 465, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Boyd, C.E., M. E. Tanner, M. Madkour, and K. Masuda, 1994. Chemical characteristics of bottom soils from freshwater and brackishwater aquaculture ponds. Journal of the World Aquaculture Society, 25:517-534.

Brady, N.C., 1990. The nature and properties of soils, 10th edition. Macmillan Publishing Company, New York, USA.

Hajek, B.F. and C.E. Boyd, 1994. Rating soil and water information for aquaculture. Aquacultural Engineering, 13:115-128.

Moyle, J.B, 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management, 20:303-320.

Munsiri, P., C.E. Boyd, and B.F. Hajek, 1995. Physical and chemical characteristics of bottom soil profiles in ponds at Auburn, Alabama, USA, and a proposed system for describing pond soil horizons. Journal of the World Aquaculture Society, 26:346-377.

Rouse, R.D., 1968. Soil testing theory and calibration for cotton, corn, soybeans and coastal bermudagrass. Bulletin 375, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Walsh, L.M. and J.D. Beaton, 1973. Soil testing and plant analysis. Soil Science Society of America, Madison, Wisconsin, USA.

Finishing System for Large Tilapia

Interim Work Plan, Thailand Study 4

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Introduction

Nile tilapia (*Oreochromis niloticus*) is cultured primarily in the semi-intensive ponds based on fertilizers or on integrated systems with livestock (Edwards, 1986; 1991). The fish-livestock integrated systems for fish production has been practiced widely for centuries (Pillay, 1992). Nile tilapia cage culture has a relatively short history (Coche, 1982), beginning in the 1970s in the Ivory Coast (Coche, 1974). Since then, the technique has spread progressively to several other regions of the world (Coche, 1982). Caged fish are usually fed with high protein diets; wastes as dissolved nutrients, uneaten feed, and metabolic products from cages are either directly or indirectly released to the surrounding environment, causing accelerated eutrophication in those waters (Beveridge, 1984; Ackefors, 1986; Lin et al., 1989). Those wastes can be reused in fish-livestock integrated systems as a valuable resource in an integrated aquaculture system to generate natural foods for culture of filter feeding species such as Nile tilapia (Lin et al., 1989; Lin, 1990). Such an integrated aquaculture system has been practiced in catfish-tilapia (Lin et al., 1989; Lin, 1990; Lin and Diana, 1995) and in tilapia-tilapia (McGinty, 1991; Yi et al., 1996; Yi and Lin, 1996) cage-cum-pond integrated culture systems.

A series of experiments were designed to develop an integrated rotation culture system in which large Nile tilapia were stocked in cages suspended in earthen ponds while small Nile tilapia were stocked outside the cages in the open pond to utilize the cage wastes and could be harvested from the open pond to restock the cages. Large Nile tilapia (> 500 g) can fetch a much higher price in some countries than smaller Nile tilapia (250-300 g) commonly produced in fertilized pond systems. Caged Nile tilapia can reach 500 g within 90 days when stocked at 50 fish/m^3 in an integrated culture system with one cage in each 330-m^3 pond with 1.0 m or 1.2 m water depth. However, the derived wastes from a single cage were insufficient to generate abundant natural foods for the growth of open-pond tilapia (Yi et al., 1996). A greater biomass of large tilapia could be accomplished by adding more cages, not stocking at high densities in cages to maximize production of both caged and open-pond tilapia, and maintaining acceptable water quality (Yi et al., 1996). Growth performance of caged and open-pond tilapia significantly decreased and increased, respectively, with the increased number of cages from 1 to 4 per pond. However, the net yield of caged tilapia in each pond leveled off with the increased biomass of caged tilapia in a pond, indicating that the carrying capacity of caged tilapia might be exceeded in the earthen ponds stocked with small tilapia at 2 fish/m^3. The highest net yield of caged tilapia and total net yield of both caged and open-pond tilapia were achieved in the ponds with two cages, but the final size did not reach the desirable market size (> 500 g) (Yi and Lin, 1996). High numbers of open-pond tilapia decreased the growth of caged tilapia (McGinty, 1991), and lowering the stocking density of open-pond tilapia may be the best way to increase the harvested size of both caged and open-pond tilapia for optimizing the tilapia-tilapia cage-cum-pond integrated culture system.

The purposes of this study were to determine effects of stocking densities of open-pond small tilapia on the growth performance of both caged and open-pond tilapia and to compare the growth performance of both large and small tilapia in the integrated culture system and mixed pond culture system.

Table 1. Experimental design.

Small Nile Tilapia in Open Ponds	Large Nile Tilapia	
	Two Cages per Pond (2 x 200 Tilapia per Pond)	*No Cage in Pond* (2 x 200 Tilapia per Pond)
Low Stocking Density (1.4 fish/m^3)	Low-Integrated	Low-Mixed
High Stocking Density (2 fish/m^3)	High-Integrated	High-Mixed

Materials and Methods

The data were collected from an experiment conducted for 84 days during July-September 1995 at the Asian Institute of Technology (AIT) in Thailand. Four hundred large tilapia (122-125 g) were stocked in 4-m^3 net cages in each of six ponds with two cages, and at large in open water in each of six ponds without cages. Small tilapia (15-16 g) were stocked at two densities, 1.4 and 2 fish/m^3, in open water of all ponds four days after the large tilapia were stocked (Table 1). The stocking density of 1.4 fish/m^3 was chosen was that the main purpose of the study was to develop a rotation system and at such a stocking density the total number of harvested open-pond tilapia in a pond was just enough to be stocked in two cages in the pond for a next culture cycle. Both large and small Nile tilapia were sex-reversed males by methyl-testosterone treatment in fry stage.

The experiment was conducted in a 2 x 2 factorial design in twelve ponds, of which eight ponds were 335 m^2 in surface area with 1.2-m water depth (Table 1). Four of those eight ponds were designated as block I and the remaining four block II. To make up a triplicate experimental design, four ponds of 394 m^2 in surface area with 1.0-m water depth were designated as block III. The water volume of each pond was approximately 330 m^3. One replication from each treatment was assigned randomly to one pond in each block. Two metal frame cages (2 x 2 x 1.2 m) covered with 2-cm mesh nylon net were suspended to a depth of 1 m in each of the six ponds with cages. The 9-m^2 bottom of shallower ponds was deepened by 20 cm below each cage to keep cage floors 20 cm off pond bottoms. Two cages were arranged at the two ends of each pond and 2 m apart from bottom lines along the pond central line. To confine floating pellets within the cages, a fine mesh polyethylene net was fixed 5 cm above to 15 cm below the water surface on the outside of each cage. A wooden or bamboo walkway connected each cage to the pond bank. The cages were covered with nylon nets to prevent fish losses from jumping or bird predation.

Water was refilled weekly to replace water loss due to seepage and evaporation. No fertilizer was added to any experimental pond. Commercial floating pellets (crude protein 30%, Charoen Pokphand Co., Ltd.) were given to cages in the integrated culture system and open water in the mixed pond culture system at 0900 and 1600 hour six days per week. Feeding rates were 3%, 2.5% and 2% body weight of large tilapia per day during the first, second, and third months, respectively. The feed ration was adjusted daily based on the mortality and biweekly sample weight of large tilapia. Small tilapia stocked in open water in the ponds without cages were not given artificial feed.

Average weights of tilapia were determined biweekly by bulk weighing 40 large and small tilapia each per pond. Large tilapia in cages were sampled by dip net and tilapia at large by seine. Tilapia were harvested, counted, and bulk weighed at the end of the experiment.

The loadings of total nitrogen and total phosphorus by tilapia waste products from cages to pond water were estimated by deducting nitrogen (N) and phosphorous (P) contents in carcasses of harvested and dead caged tilapia from those in feed input.

Water samples integrated from the entire water column were taken biweekly from a platform at the center part of each pond at about 0900 hours for the analysis of pH, total ammonia-nitrogen and chlorophyll-*a* (APHA, 1985). Un-ionized ammonia-nitrogen was calculated by a conversion table for pH and temperature (Boyd, 1990). Water temperature and DO concentrations were measured

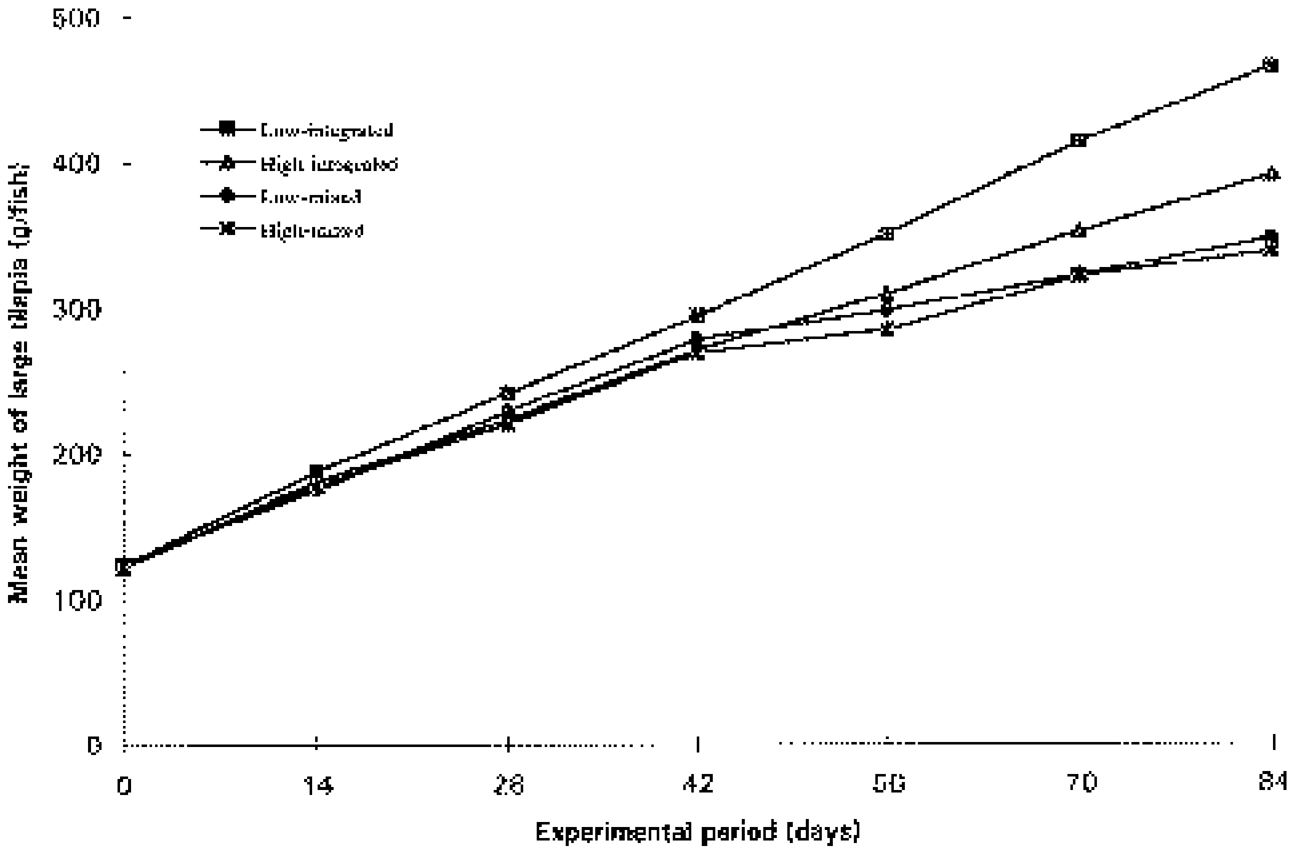

Figure 1. Growth of large Nile tilapia in the integrated and mixed pond culture systems over the experimental period.

in situ biweekly at 0600-0700 and 1500-1600 hours with an oxygen meter (YSI model 54).

Data were analyzed statistically by analysis of variance and regression (Steele and Torrie, 1980) using the Statgraphics 7 statistical software package. Differences were considered significant at an alpha of 0.05. All means were given with ± 1 standard error (S.E.).

Results

Effects of Stocking Densities of Open-pond Tilapia

Stocking densities of open-pond tilapia had significant effects on the growth of both caged and open-pond tilapia, and also on the feed conversion ratio in the integrated culture system (Tables 2, 3, and 4). Caged tilapia had higher survival in the low density treatment (98.8%) than in the high density treatment (97.5%), but there were no significant differences. The growth of caged tilapia began to differ at the time of the first sampling during the growout period (Figure 1). Mean individual weight and daily weight gain were significantly greater in the low density treatment (465 g and 4.06 g/fish) than in the high density treatment (391 g and 3.20 g/fish), giving significantly higher net yield in the low density treatment (4.3 t/ha/crop) than in the high density treatment (3.3 t/ha/crop). Feed conversion ratio was significantly lower in the low density treatment (1.22) than in the high density treatment (1.49).

Survival of open-pond tilapia was higher in the low density treatment (92.0%) than in the high density treatment (86.2%) but without significant differences. The growth of open-pond tilapia in the low density treatment with a daily weight gain of 1.35 g/fish and mean individual weight of 124 g was significantly faster than in the high density treatment with a daily weight gain of 1.02 g/fish and mean individual weight of 97 g (Figure 2). However, the extrapolated net yield of open-pond tilapia was similar in both treatments, that is, 1.6 and 1.5 t/ha/crop in the low and high density treatments, respectively.

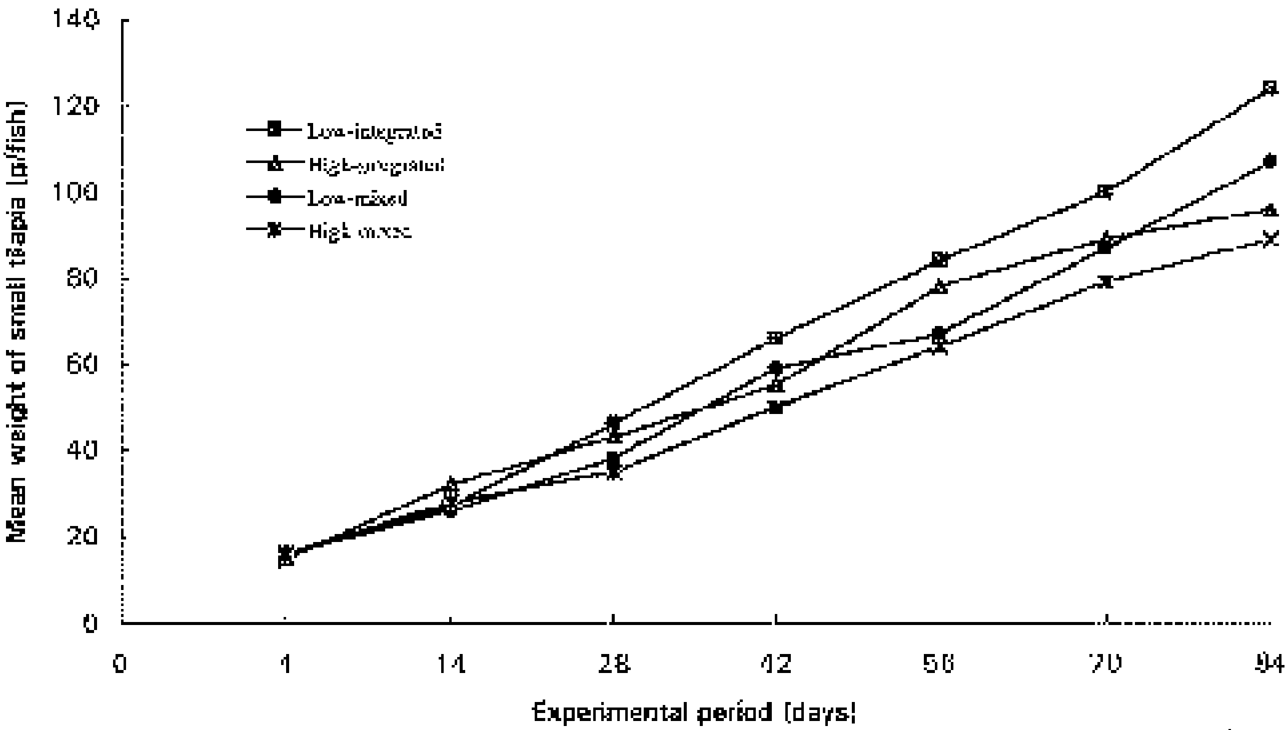

Figure 2. Growth of small Nile tilapia in the integrated and mixed pond culture systems over the experimental period.

Table 2. Growth performance of large Nile tilapia stocked in cages in the integrated culture system and in open water in the mixed culture system.

Performance Measures	Treatments			
	Low-Integrated	*High-Integrated*	*Low-Mixed*	*High-Mixed*
STOCKING				
Total No. (fish/pond)	400	400	400	400
Total Biomass (kg/pond)	49.5 ± 1.6	48.9 ± 2.3	50.0 ± 1.3	49.4 ± 0.3
Mean Wt. (g/fish)	124 ± 4.8	125 ± 3.2	122 ± 5.2	124 ± 0.7
HARVEST				
Total Biomass (kg/pond)	183.8 ± 4.0^{a}	137.7 ± 4.0^{c}	152.4 ± 4.8^{b}	134.6 ± 1.8^{c}
Mean Wt. (g/fish)	465 ± 11.5^{a}	347 ± 10.5^{c}	391 ± 19.4^{b}	338 ± 4.3^{c}
WEIGHT GAIN				
Total Biomass Gain (kg/pond)	134.4 ± 2.4^{a}	87.6 ± 3.5^{c}	103.5 ± 2.6^{b}	85.3 ± 1.7^{c}
Mean Wt. Gain (g/fish)	341 ± 7.6^{a}	221 ± 9.2^{c}	269 ± 13.9^{b}	215 ± 4.2^{c}
Daily Wt. Gain (g/fish/day)	4.06 ± 0.09^{a}	2.64 ± 0.11^{c}	3.20 ± 0.1^{b}	2.56 ± 0.05^{c}
Net Yield (t/ha/crop)	4.3 ± 0.1^{a}	2.8 ± 0.1^{c}	3.3 ± 0.1^{b}	2.7 ± 0.1^{c}
Survival (%)	98.8 ± 0.5	99.3 ± 0.1	97.5 ± 1.7	99.5 ± 0.5
Feed Conversion Ratio (kg feed/kg fish)	1.22 ± 0.02^{a}	1.70 ± 0.03^{c}	1.49 ± 0.01^{b}	1.71 ± 0.07^{c}
Gross Yield (t/ha/crop)	5.9 ± 0.1^{a}	4.4 ± 0.1^{c}	4.9 ± 0.2^{b}	4.3 ± 0.1^{c}

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

Table 3. Growth performance of small Nile tilapia stocked in open water in the integrated culture system and the mixed culture system.

Performance Measures	Treatments			
	Low-Integrated	*Low-Mixed*	*High-Integrated*	*High-Mixed*
STOCKING				
Density (fish/m^3)	1.4	1.4	2	2
Total No. (fish/pond)	462	462	660	660
Total Biomass (kg/pond)	7.2 ± 0.6	7.3 ± 0.3	10.0 ± 0.5	10.6 ± 0.9
Mean Wt. (g/fish)	16 ± 1.3	16 ± 0.6	15 ± 0.8	16 ± 1.4
HARVEST				
Total Biomass (kg/pond)	52.6 ± 0.7^{ab}	41.8 ± 2.4^{c}	54.7 ± 2.4^{a}	50.9 ± 1.7^{b}
Mean Wt. (g/fish)	124 ± 1.8^{a}	107 ± 8.3^{b}	97 ± 8.3^{bc}	89 ± 7.5^{c}
WEIGHT GAIN				
Total Biomass Gain (kg/pond)	45.4 ± 0.4^{a}	34.5 ± 2.3^{c}	44.7 ± 1.9^{a}	40.3 ± 1.7^{b}
Mean Wt. Gain (g/fish)	108 ± 3.1^{a}	92 ± 8.0^{b}	81 ± 7.7^{bc}	73 ± 6.1^{c}
Daily Wt. Gain (g/fish/day)	1.35 ± 0.04^{a}	1.14 ± 0.10^{b}	1.02 ± 0.10^{bc}	0.92 ± 0.08^{c}
Net Yield (t/ha/crop)	1.6 ± 0.0^{a}	1.2 ± 0.1^{c}	1.5 ± 0.1^{a}	1.4 ± 0.0^{b}
SURVIVAL (%)	92.0 ± 2.6	84.8 ± 10.1	86.2 ± 4.5	86.8 ± 7.4
GROSS YIELD (t/ha/crop)	1.8 ± 0.0^{a}	1.4 ± 0.1^{c}	1.8 ± 0.1^{a}	1.7 ± 0.1^{b}

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

The extrapolated total net yield including both caged and open-pond tilapia in the integrated culture system were significantly higher in the low density treatment (5.5 t/ha/crop) than in the high density treatment (4.5 t/ha/crop). The overall feed conversion ratio in the low density treatment was 0.92, which was significantly better than that in the high density treatment (1.04).

The total nitrogen and phosphorous contained in waste products from caged tilapia during the 84-day culture period were 4.86 and 5.00 kg N and 1.03 and 1.09 kg P in the low and high density treatments, respectively. Accordingly, those nutrient outputs fertilized the ponds at rates of 1.75 and 1.80 kg N/ha/day, and 0.37 and 0.39 kg P/ha/day, giving N:P ratios of 4.73 and 4.58 in the low and high density treatments, respectively.

Water temperature and pH in all ponds with cages ranged from 28.4 to 31.5°C, and from 7.0 to 7.8°C, respectively, throughout the experiment. The measured DO concentrations at dawn were apparently higher in the low density treatment than in the high density treatment throughout the experiment (Figure 3). Un-ionized NH_3-N concentration increased gradually from the initial level of 0 mg/l to the final levels of 0.07 and 0.05 mg/l in the low and high density treatments, respectively, throughout the experiment (Figure 4). The phytoplankton standing crops as expressed in chlorophyll-*a* concentrations were generally low but higher in the low density treatment than in the high density treatment (Figure 5).

Comparisons Between the Integrated and Mixed Pond Culture Systems

Large tilapia grew significantly better in cages in the integrated culture system than in open water in the mixed pond culture system at the same level of stocking densities of small tilapia (Table 2 and Figure 1). However, there were no significant differences in survival for all treatments, which

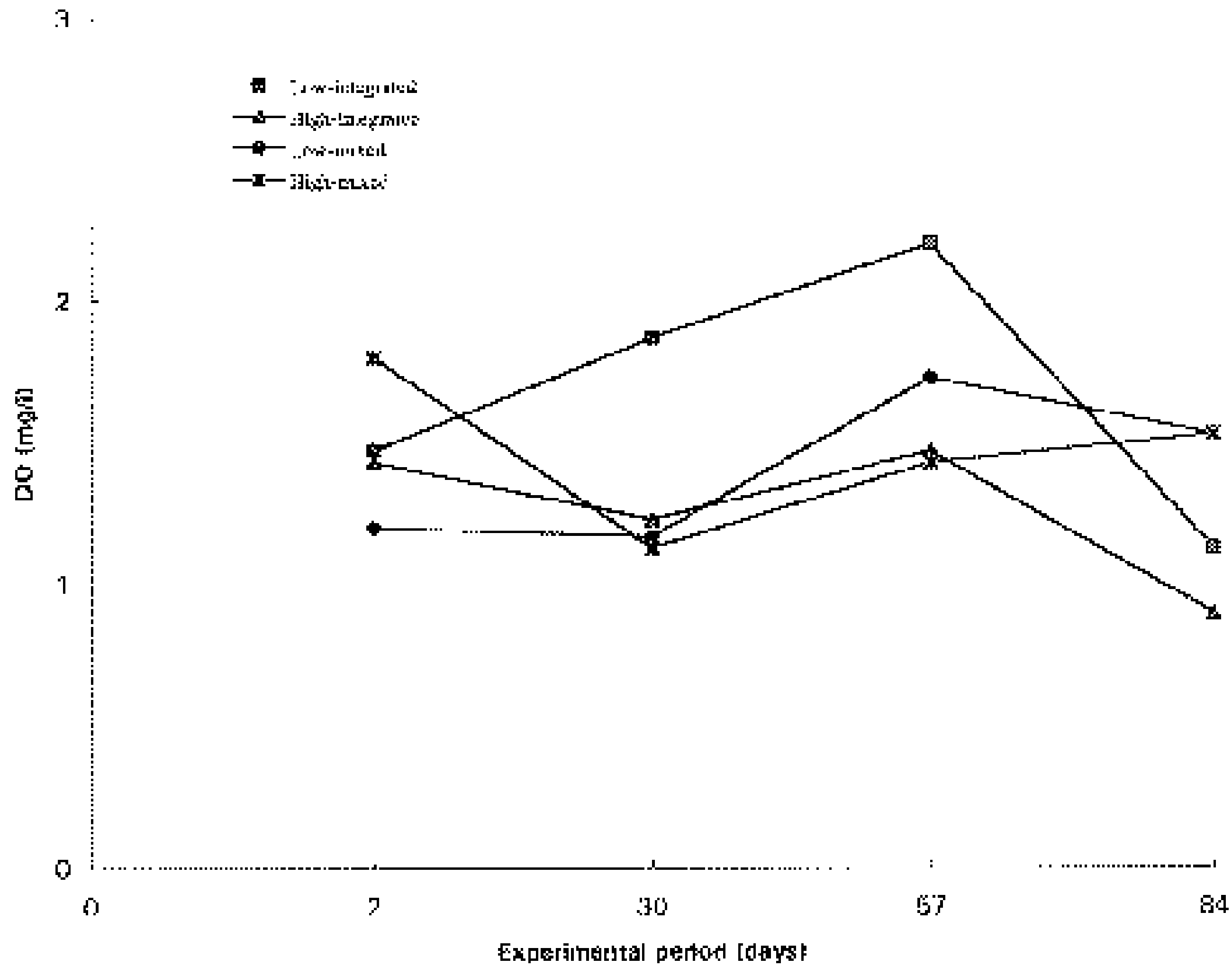

Figure 3. Fluctuations in DO at dawn in all treatments throughout the experimental period.

ranged from 97.5% to 99.5%. The extrapolated net yields of large tilapia in the integrated culture system were 4.3 in the low density treatment and 3.3 t/ha/crop in the high density treatment; these were significantly higher than those in the low (2.8 t/ha/crop) and high (2.7 t/ha/crop) density treatments in the mixed pond culture system. Feed conversion ratios were significantly lower in the integrated culture system than those in the mixed pond culture system. In the integrated culture system, the growth performance of large tilapia in the low density treatment was significantly better than in the high density treatment; however, it was similar between the low and high density treatments in the mixed pond culture system.

Survival of small tilapia, ranging from 84.8% to 92.0%, was not significantly different among all treatments (Table 3). At the same stocking density, the growth of small tilapia was significantly faster in the integrated culture system with daily weight gains of 1.35 and 1.02 g/fish and mean individual weights of 124 and 97 g than in the mixed pond culture system with daily weight gains of 1.14 and 0.92 g/fish and mean individual weights of 107 and 89 g in the low and high density treatments, respectively (Figure 2). In spite of the significantly better growth of small tilapia in the low density treatment (1.35 g/fish/day) than in the high density treatment (1.02 g/fish/day) in the integrated culture system, there were no significant differences in net yields between them (1.6 and 1.5 t/ha/crop, respectively). In the mixed pond culture system, however, the net yield of small tilapia in the high density treatment (1.4 t/ha/crop) was significantly higher than in the low density treatment (1.2 t/ha/crop), even though the growth of small tilapia was significantly faster in the low density treatment (1.14 g/fish/day) than in the high density treatment (0.92 g/fish/day).

Table 4. Combined growth performance of both large and small Nile tilapia cultured in the integrated culture system and the mixed pond culture system.

Performance Measures	Treatments			
	Low-Integrated	*Low-Mixed*	*High-Integrated*	*High-Mixed*
Initial Fish Biomass (kg/pond)	56.7 ± 2.1	57.4 ± 1.2	59.0 ± 2.2	60.0 ± 0.7
Final Fish Biomass (kg/pond)	236.4 ± 4.3[a]	179.5 ± 4.3[c]	207.1 ± 5.1[b]	185.3 ± 0.6[c]
Fish Biomass Gain (kg/pond)	179.7 ± 2.2[a]	122.1 ± 3.4[c]	148.1 ± 2.9[b]	125.5 ± 1.3[c]
Net Fish Yield (t/ha/crop)	5.8 ± 0.1[a]	4.0 ± 0.1[c]	4.8 ± 0.1[b]	4.1 ± 0.1[c]
Gross Yield (t/ha/crop)	7.8 ± 0.1[a]	5.9 ± 0.1[c]	6.8 ± 0.2[b]	6.1 ± 0.1[c]
Overall FCR	0.92 ± 0.01[a]	1.22 ± 0.01[d]	1.04 ± 0.01[b]	1.16 ± 0.03[c]

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

The combined extrapolated net yields of both large and small tilapia in the integrated culture system (5.8 and 4.8 t/ha/crop in the low and high density treatments, respectively) were significantly higher than in the mixed pond culture system (4.0 and 4.1 t/ha/crop in the low and high density treatments, respectively) at the same level of stocking density. A significantly better overall feed conversion ratio was achieved in the integrated culture system (0.92 and 1.04) than in the mixed pond culture system (1.22 and 1.16) in the low and high density treatments, respectively. There were no significant differences for all combined growth performance measures except overall feed conversion ratio between the low and high density treatments in the mixed pond culture system; however, all combined growth performance measures in the integrated culture system were significantly better in the low density treatment than in the high density treatment (Table 4).

Water temperature and pH in all treatments ranged from 28.0 to 31.5°C and 7.0 to 7.8°C, respectively, throughout the experimental period. The measured DO concentrations at dawn were apparently higher in the low density treatment in the integrated culture system than other treatments in most of the experimental period; however, DO concentrations in both low and high density treatments in the mixed pond culture system were higher than those in the integrated culture system at the end of the present experiment (Figure 3). Un-ionized NH_3-N concentrations increased gradually from the initial level of 0.00 mg/l to the final level of 0.03-0.07 mg/l for all treatments, which was higher in the integrated culture system than in the mixed pond culture system (Figure 4).

The phytoplankton standing crops as expressed in chlorophyll-*a* concentrations were lower in the integrated culture system than in the mixed pond culture system at the same level of stocking densities (Figure 5).

Discussion

The growth performance (excepting the survival rate) of caged tilapia in the low density treatment was significantly better than in the high density treatment. This confirmed that high numbers of open-pond tilapia decreased growth of caged tilapia (McGinty, 1991). The final mean individual weight of caged tilapia in the low density treatment (465 g) in this experiment was slightly smaller than the desirable market size (> 500 g). This was due to the smaller stocking size (124 g) and shorter growout period (84 days) compared with those (141-152 g and 90 days) in an earlier experiment (Yi et al., 1996). The present experiment was terminated 6 days earlier than the planned 90 days because AIT was facing the threat of a flood. The daily weight gain of caged tilapia in the low density treatment was slightly lower than in ponds with one cage in earlier experiments (Yi et al., 1996; Yi and Lin, 1996); however, it was still much higher than the values reported previously for intensive cage culture of Nile tilapia in ponds (Guerrero, 1979; Guerrero, 1980; McGinty, 1991), in lakes (Coche, 1977, and Campbell, 1978, cited by Coche, 1982) or in thermal effluent (Philippart et al., 1979, cited by Coche, 1982). Feed conversion ratio in the low density treatment was similar to that in ponds with one cage in an earlier experiment (Yi et al., 1996), and both were the lowest values among all the

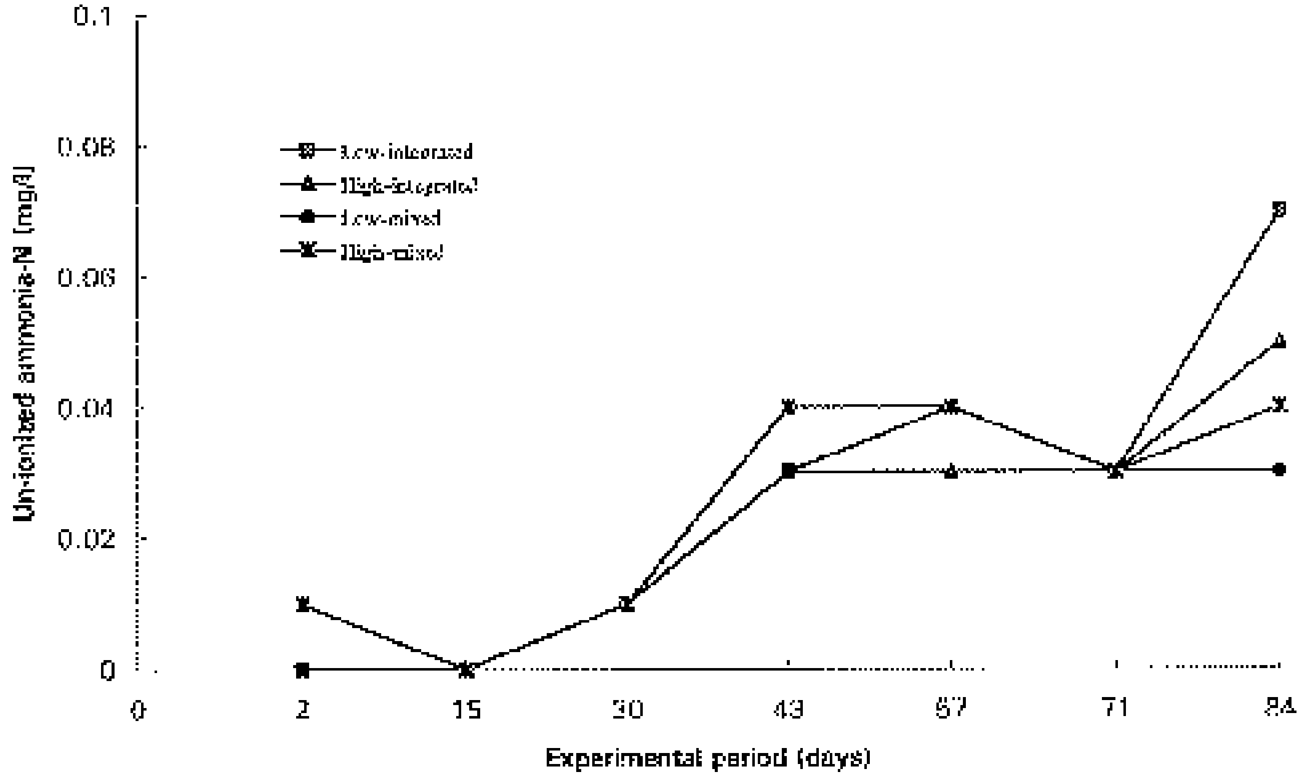

Figure 4. Fluctuations in un-ionized ammonia nitrogen at 0900 hr in all treatments throughout the experimental period.

series of experiments in this study (Yi et al., 1996; Yi and Lin, 1996), and also lower than that reported by Carro-Anzalotta and McGinty (1986), Guerrero (1979, 1980) and McGinty (1991) in ponds, and by Coche (1977, cited by Coche, 1982) and Campbell (1978, cited by Coche, 1982) in lakes. The better growth performance of caged tilapia in the low density treatment was due probably to the higher DO concentrations at dawn in the low density treatment than in the high density treatment.

Even though daily weight gain of open-pond tilapia was significantly higher in the low density treatment than in the high density treatment, there were no significant differences in net yields between these two treatments, due to the higher fish number and lower daily weight gain in the high density treatment. The daily weight gain of open-pond tilapia in the low density treatment was similar to that in ponds with three cages, and much higher than that in ponds with the lower and even same biomass of caged tilapia (one and two cages per pond) in earlier experiments (Yi et al., 1996; Yi and Lin, 1996). However, this value was still lower than the 2.4-2.7 g/fish in a catfish-tilapia cage-cum-pond integrated system (Lin, 1990) and also lower than 2.3 g/fish in a tilapia-tilapia cage-cum-pond integrated system (McGinty, 1991) due mainly to higher stocking density of open-pond tilapia in this experiment.

The extrapolated net yield for both caged and open-pond tilapia in the low density treatment was significantly higher than in the high density treatment and in earlier experiments (Yi et al., 1996; Yi and Lin, 1996) due to better growth performance of both open-pond and caged tilapia in this experiment; it was also higher than in a tilapia-tilapia cage-cum-pond integrated system McGinty (1991).

Further, lowering the stocking density of open-pond tilapia may increase harvested size of open-pond tilapia themselves, but may not achieve the higher total yield, which can be seen in the results reported by McGinty (1991). Also the main purpose of this study was to fatten large tilapia in cages to 500 g size and develop an integrated rotation system for utilizing cage wastes by small tilapia.

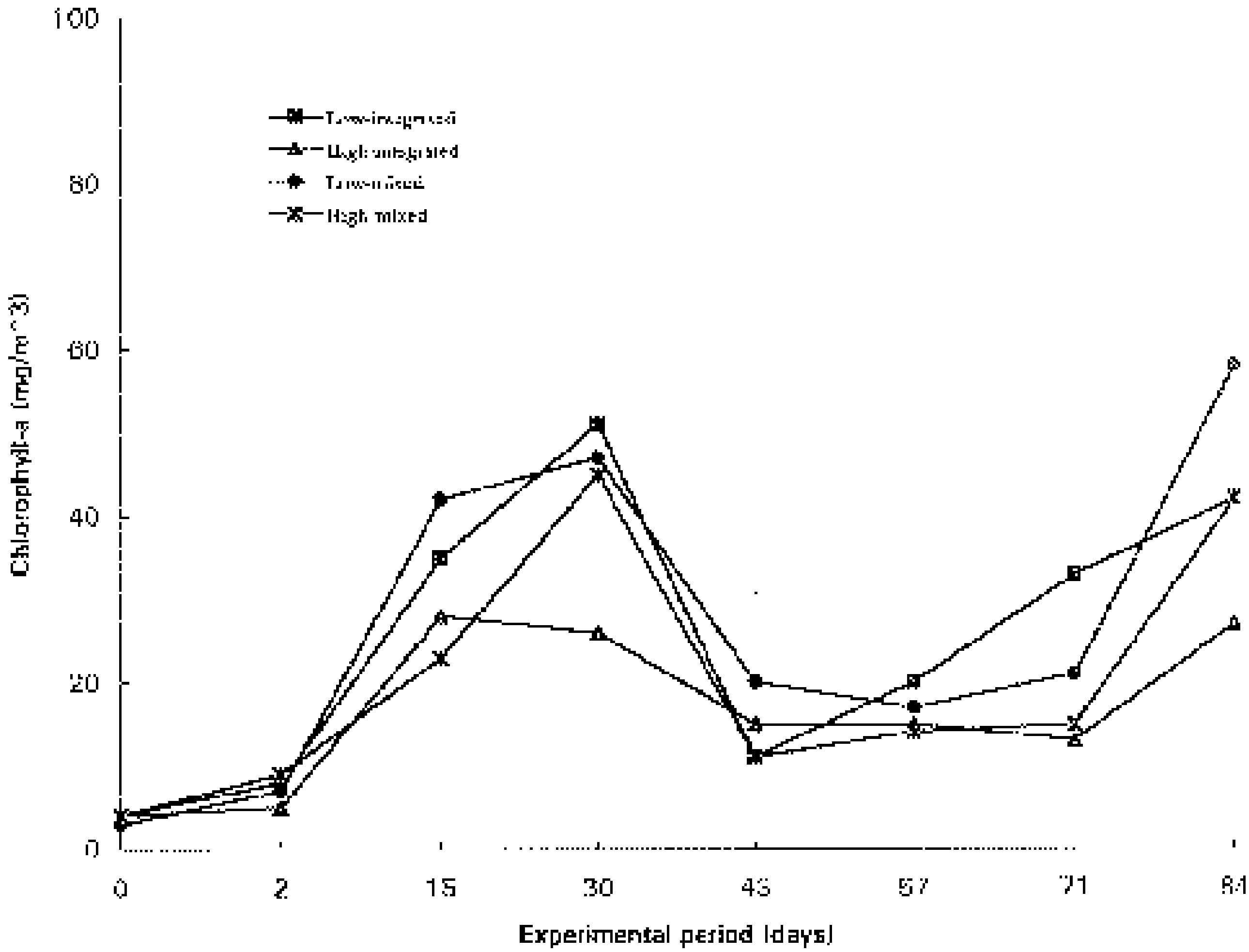

Figure 5. Fluctuations in chlorophyll-*a* at 0900 hr in all treatments throughout the experimental period.

At the 1.4 fish/m^3 stocking density of open-pond tilapia, the total number of harvested open-pond tilapia in a pond is just enough to be stocked in two cages in the pond and the size at harvest of open-pond tilapia is also just large enough to restock the cages for a next culture cycle, thus making the integrated culture system rotate. Therefore, the low density treatment was the optimal tilapia-tilapia cage-cum-pond integrated rotation culture system.

There were no significant differences in the survival of large tilapia between the integrated culture system and mixed pond culture system although the survival was slightly lower in the former two levels of stocking densities of small tilapia. However, the growth of large tilapia was significantly faster in the integrated culture system than in the mixed pond culture system at two levels of stocking densities of small tilapia in terms of daily weight gain, mean individual weight, and net and gross yields. This proved the statement that cage culture accelerates fish growth compared to the traditional open-water aquaculture (Schmittou, 1993). Furthermore, this rapid growth rate did not sacrifice the feed conversion ratio. In fact, feed conversion ratio in the integrated culture system was significantly better than that in the mixed pond culture system. The growth performance of small tilapia was also significantly better in the integrated culture system than in the mixed pond culture system at the same stocking density of small tilapia. Compared with the common pond culture system for tilapia, one major advantage is the possibility of controlling unwanted recruitment in the integrated culture system. In most cage culture, the initial stocking size of tilapia is quite small (Coche, 1982), and the fish consume costly feed before reaching sizes 100-150 g. However, Diana et al. (1996) indicated that supplemental feeding of Nile tilapia starting at 100-150 g size is probably the most effective to produce large-sized tilapia. In addition, feed costs usually account for the largest portion of total costs in the intensive fish culture. It is apparent that less working capital is needed in the integrated culture system than in other intensive culture systems due to harvesting and marketing tilapia every three months in the integrated culture system, and more frequent marketing also can make products get better prices. Therefore, this tilapia-tilapia cage-cum-pond integrated rotation system is particularly appropriate for small-scale farmers in countries such as Thailand, where large tilapia (> 500 g) fetch much higher market price than 250-300 g tilapia commonly harvested in fertilized ponds.

In the integrated culture system, the growth performance of large tilapia was significantly better in the low density treatment than in the high density treatment, which confirmed the statement that high numbers of open-pond tilapia decreased the growth of caged tilapia (McGinty, 1991). However, lowering stocking densities of small tilapia did not increase the growth of large tilapia in the mixed pond culture system, and small tilapia showed slower growth in the mixed pond culture system than in the integrated culture system. These are similar to the results reported by Knud-Hansen and Lin (in press) that the growth of adult Nile tilapia would not be affected by the co-existing fingerlings, but not the reverse. Their experiment was conducted in highly fertilized ponds, and it is difficult to imagine that adult tilapia limited fingerling growth by out-competing fingerlings for phytoplankton. They stated that it is more probable that territorial aggressive behavior noted among male tilapia (Balarin and Haller, 1982; Owusu-Frimpong, 1987) occurred only between fish of similar size or greater. Fishelson (1983) observed a strong correlation between social rank and aggressive activity among male tilapia. Fish high up on the hierarchy needed only to swim by lesser fish to maintain dominance. In the mixed pond culture system of the present experiment, supplemental feeds were given by pouring into the center of ponds. Large tilapia apparently dominated in getting feed, and small tilapia seemed to have little chance to getting feed. Thus, adults would not be affected by fingerlings. On the other hand, small tilapia in the mixed pond culture system showed a density-dependent growth pattern and a similar positive relationship between initial stocking density and net yield to those reported by Knud-Hansen (in press) and Milstein et al. (1988), indicating food limitation did not occur. Furthermore, small tilapia grew better when large tilapia were confined in cages than when they were mixed together with small tilapia. This may indicate that the co-existing large tilapia would affect the growth of small tilapia by territorial aggressive behavior. The results of this experiment may suggest that the competition for space is probably the main reason why small tilapia would be affected by large tilapia, but not the reverse at least in the ponds receiving supplemental feeds.

Literature Cited

Ackefors, H., 1986. The impact on the environment by cage farming in open water. J. Aqua. Trop., 1:25-33.

APHA, 1985. Standard Methods for the Examination of Water and Wastewater. 16th Edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, D.C., 1268 pp.

Balarin, J.D. and R.D. Haller, 1982. The intensive culture of tilapia in tanks, raceways, and cages. In: J.F. Muir and R.J. Roberts (Editors), Recent Advances in Aquaculture. Westview Press, Boulder, Colorado, USA.

Beveridge, C.M., 1984. Cage and pen fish farming: Carrying capacity models and environmental impacts. FAO Fisheries Technical Paper No. 255. FIRI/222. FAO, Rome, 131 pp.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Auburn University, Auburn, Alabama, 482 pp.

Carro-Anzalotta, A.E. and A.S. McGinty, 1986. Effects of stocking density on growth of *Tilapia nilotica* cultured in cages in ponds. Journal of the World Aquaculture Society, 17:52-57.

Coche, A.G., 1974. Lage Kossou Development Project, Ivory Coast. FAO Aquacul. Bull., 6(2/3):28.

Coche, A.G., 1982. Cage culture of tilapia. In: R.S.V. Pullin and R.H. Lowe-McConnell (Editors), The Biology and Culture of Tilapia. ICLARM, Manila, Philippines.

Diana, J.S., Lin, C.K. and Yang Yi, In Press. Timing of supplemental feeding. Journal of the World Aquaculture Society.

Edwards, P., 1986. Duck/fish integrated farming systems. In: D.J. Farell and P. Stapleton (Editors), Duck Production, Science and World Practice. University of New England.

Edwards, P., 1991. Integrated fish farming. Infofish International, pp. 45-51.

Fishelson, F., 1983. Social behaviour of adult tilapia fish in nature and in captivity (Israel). In: L. Fishelson and Z. Yaron (Editors), International Symposium on Tilapia in Aquaculture. Tel Aviv University, Tel Aviv, Israel.

Guerrero, R.D., 1979. Cage culture of tilapia in the Philippines. Asian Aquaculture, 2(11):6.

Guerrero, R.D., 1980. Studies on the feeding of *Tilapia nilotica* in floating cages. Aquaculture, 20:169-175.

Knud-Hansen, C.F. and C.K. Lin, In Press. Strategies for stocking Nile tilapia (*Oreochromis niloticus*) in fertilized ponds. In: Proceedings of the Third International Symposium on Tilapia in Aquaculture. Abidjan, Cote d'Ivoire.

Lin, C.K., K. Jaiyen, and V. Muthuwan, 1989. Integration of intensive and semi-intensive aquaculture: Concept and example. Thai Fisheries Gazette, pp. 425-430.

Lin, C.K., 1990. Integrated culture of walking catfish (*Clarias macrocephalus*) and tilapia (*Oreochromis niloticus*). In: R. Hirano and I. Hanyu (Editors), The Second Asian Fisheries Forum, Asian Fisheries Society, Manila, Philippines.

Lin, C.K. and J.S. Diana, 1995. Co-culture of catfish (*Clarias macrocephalus x C. gariepinus*) and tilapia (*Oreochromis niloticus*) in ponds. Aquat. Living Resour., 8(4):449-454.

McGinty, A.S., 1991. Tilapia production in cages: Effects of cage size and number of noncaged fish. The Progressive Fish-Culturist, 53:246-249.

Milstein, A., G. Hulata, and G.W. Wohlfarth, 1988. Canonical correlation analysis of relationship between management inputs and fish growth and yields in polyculture. Aqua. and Fish. Manag., 19:13-24.

Owusu-Frimpong, M., 1987. Breeding behavioral pattern of the lake fish *Tilapia discolour* Gunther (Teleosti, Cichlidae) in captivity. J. Fish Biol., 30:1-5.

Pillay, T.V.R., 1992. Aquaculture and the Environment. Fishing News Books, 189 pp.

Schmittou, H.R., 1993. High Density Fish Culture in Low Volume Cages. Aquaculture, American Soybean Association, Vol. AQ41 1993/7, 78 pp.

Steele, R.G.D. and J.H. Torrie, 1980. Principles and Procedures of Statistics, Second Edition. McGraw-Hill, New York, 633 pp.

Yang Yi, C.K. Lin, and J.S. Diana, In Press. Effects of stocking densities on growth of caged adult Nile tilapia (*Oreochromis niloticus*) and on yield of small Nile tilapia in open water in earthen ponds. Aquaculture.

Yang Yi and C.K. Lin, Submitted. Effects of biomass of caged Nile tilapia (*Oreochromis niloticus*) and aeration on the growth and yields of all Nile tilapia in an integrated culture system with small Nile tilapia at large in earthen ponds. Manuscript submitted to Aquaculture.

Polyculture in Deep Ponds

Interim Work Plan, Thailand Study 3

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Introduction

Fish ponds constructed in rain-fed areas of Northeast Thailand normally have a depth ranging from 2 to 3 meters. Those small ponds are filled with rain water during the wet season, and depth reduces gradually over the dry period. Small tropical ponds with a water depth greater than 1.5 m normally exhibit persistent thermal stratification (Szyper and Lin, 1990). Consequently, nutrient inputs from fertilization and regeneration to stimulate phytoplankton production probably accumulate in the hypolimnion. Stratification can also result in a severe oxygen deficit in the bottom water, especially in highly productive ponds systems. Because Nile tilapia is primarily a plankton feeder, its low efficiency in utilizing detrital material from the pond bottom often results in wasting resources for fish production. Addition of a large-sized bottom feeder such as the common carp to tilapia culture ponds may facilitate mixing of hypolimnetic water, nutrient upwelling, and increased fish production.

The objective of this experiment was to assess the effect of carp-tilapia polyculture on water quality and fish yield in deep, rain-fed ponds.

Materials and Methods

The experiment was conducted in twelve 800 m^2 ponds at the Department of Fisheries (DOF)-Udorn Thani Station, Thailand. Four experimental treatments conducted in triplicate were as follows:

- (T1) ponds stocked with Nile tilapia at 2 fish/m^2;
- (T2) ponds stocked with Nile tilapia at 2 fish/m^2 and common carp at a rate of 1000 carp/ha;
- (T3) ponds stocked with Nile tilapia at 2 fish/m^2 and common carp at 2000 carp/ha; and
- (T4) ponds stocked with Nile tilapia at 2 fish/m^2 and common carp at 3000 carp/ha.

All treatments were completely randomized. Sex-reversed, all-male Nile tilapia with an average weight of 4-5 g and common carp with an average weight of 450-500 g were stocked on August 2, 1995. All ponds were fertilized weekly with chicken manure at 250 (dry matter) kg/ha/week supplemented with urea and TSP to adjust the loading rate at 24 kg N/ha/week and 7 kg P/ha/week. At the beginning, ponds were filled up to a water level of 3 m, and then for the remaining period of the experiment, no water was added except through rainfall.

Fish growth was measured monthly by sampling 50 fish from each pond. Individual weight and length were taken. The chemical and physical conditions of pond water were also monitored according to standard CRSP protocols stated in Work Plan Seven. Fish were harvested on February 3, 1996, after 186 days of culture.

Table 1. Mean water quality paramenters of experimental period in different treatments.

Variables	T1	T2	T3	T4
DO (mg/l, 0600 h)	1.9 ± 0.3	2.0 ± 0.3	2.0 ± 0.2	2.2 ± 0.2
DO (mg/l, 1800 h)	5.8 ± 0.2	4.4 ± 0.6	5.2 ± 0.5	5.0 ± 0.5
Temperature Range (°C)	23.4 ± 33.2	23.3 ± 32.7	23.5 ± 33.2	23.7 ± 32.6
pH Range	8.2 ± 10.0	8.3 ± 9.9	7.9 ± 9.8	7.6 ± 9.8
Alkalinity (mg/l)	94.5 ± 8.1	113.9 ± 13.8	100.4 ± 8.2	116.4 ± 11.8
TAN (mg/l)	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.2	0.3 ± 0.1
NO_2-N (mg/l)	1.0 ± 0.3	1.4 ± 0.5	0.8 ± 0.2	0.7 ± 0.3
TKN (mg/l)	6.0 ± 2.2	6.1 ± 1.7	6.0 ± 2.1	4.6 ± 1.1
TP (mg/l)	1.1 ± 0.1	1.1 ± 0.1	2.1 ± 0.9	1.0 ± 0.1
SRP (mg/l)	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1
Chlorophyll-*a* (µg/l)	294.6 ± 109.9	321.7 ± 137.0	214.9 ± 53.3	250.9 ± 72.1
TSS (mg/l)	54.6 ± 5.8	67.1 ± 6.8	65.3 ± 5.6	61.5 ± 7.2
TVS (mg/l)	27.98 ± 7.6	21.6 ± 2.1	24.3 ± 4.7	50.6 ± 26.8

Values are means ± S.E. (n = 3 for each treatment) for each pond's water quality.

One-way analysis of variance was used to sort out the effect of treatment on water quality and fish yield. Differences were considered significant at an alpha level of 0.05.

Results

Water Quality

Pond water temperature and dissolved oxygen (DO) concentration between surface and bottom water for the monthly data were not significantly different ($p > 0.05$) among the treatments. Among pond water quality parameters measured (Table 1), DO values in all treatments were most variable, ranging from 1.1-13.3 mg/l with occasional drops below 0.5 mg/l towards the end of the culture period in some ponds. The mean total alkalinity value in all treatments ranged between 94.5-116.4 mg/l $CaCO_3$ with a peak at the end of the culture period. Mean TKN and chlorophyll-*a* concentration in all the treatments showed increase towards the end of culture period (Figures 2 and 5).

Mean TAN in all treatments remained in the acceptable range (Table 1) and fluctuated throughout the experimental period with a decline towards the end of culture (Figure 1). Statistical analysis showed that there were no significant differences ($p > 0.05$) for TAN, TKN, TP and chlorophyll-*a* concentrations among the treatments. The results of the experiment showed that the introduction of common carp in polyculture with Nile tilapia did not significantly affect major water quality parameters.

Fish Production

Fish growth performance of Nile tilapia was not significantly different ($p > 0.05$) among monocultured and polycultured treatments (Table 2). The maximum mean final weight of tilapia ranged from 123.9 to 164.9 g/fish and of common carp from 301.0 to 422.5 g/fish, and they were not significantly different ($p > 0.05$) among treatments. Results of the experiment showed that in all polycultured treatments, common carp lost weight during the experimental period. The total net yields (Table 2) were also not significantly different ($p > 0.05$) among treatments. This shows that the introduction of common carp for polyculture with Nile tilapia could not increase the net biological yield when compared to the monoculture of tilapia.

Discussion

Rain-fed ponds are usually built deep to maintain the water level during dry season. In small tropical ponds with greater depth density stratification, oxygen depletion in the hypolimnion is more likely (Szyper and Lin, 1990; Szyper, 1995). Mechanical mixing or bioturbation of pond water are usually suggested to overcome the problems of stratification

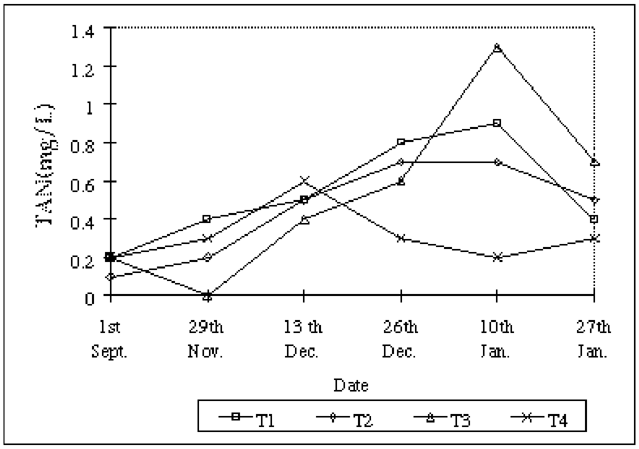

Figure 1. Mean total ammonia nitrogen (TAN) (mg/l) measured at different dates in different treatments.

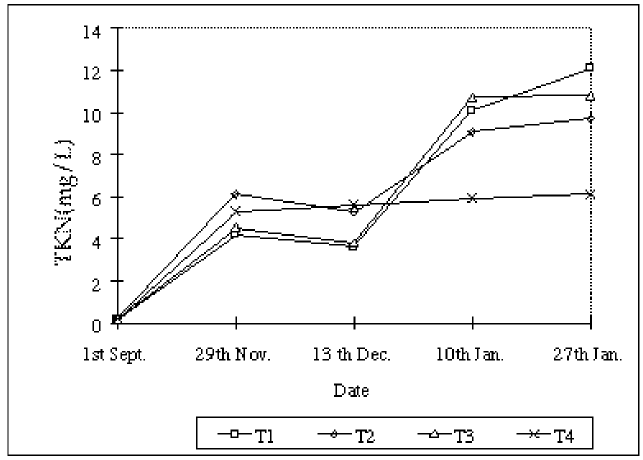

Figure 2. Mean total kjeldahl nitrogen (TKN) (mg/l) measured at different dates in different treatments.

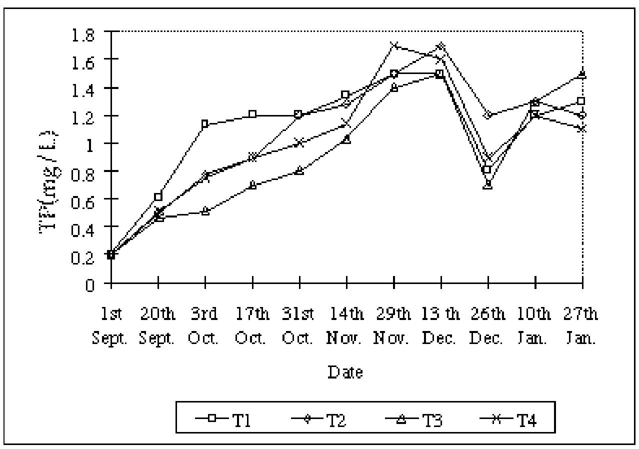

Figure 3. Mean total phosphorus (TP) (mg/l) measured at different dates in different treatments.

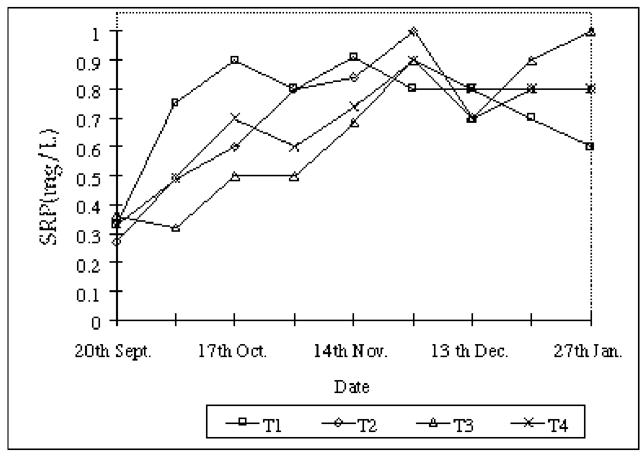

Figure 4. Mean soluble reactive phosphorus (SRP) (mg/l) measured at different dates in different treatments.

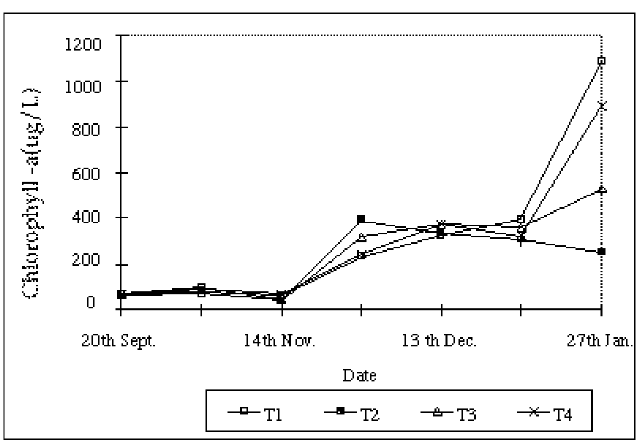

Figure 5. Mean chlorophyll-*a* concentration (µg/l) measured at different dates in different treatments.

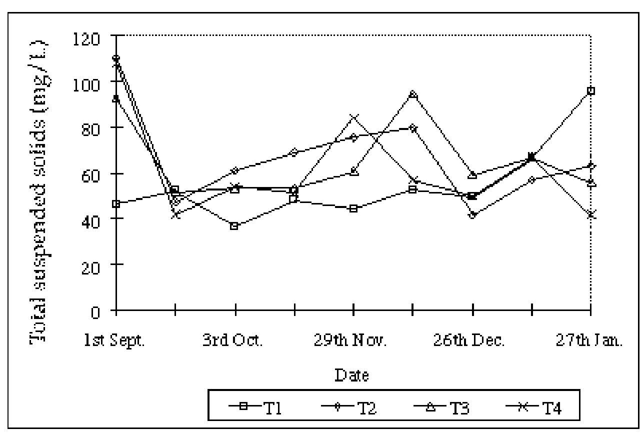

Figure 6. Mean total suspended solids (mg/l) measured at different dates in different treatments.

Table 2. Growth performance and net fish yield in different treatments.

Variable	T1	T2	T3	T4
STOCKING				
Tilapia				
Density (fish/m^2)	2	2	2	2
Total No.	1600	1600	1600	1600
Mean Weight (g/fish)	6.7 ± 0.0	4.6 ± 0.3	4.7 ± 0.2	4.4 ± 0.1
Total Weight (kg/pond)	10.7 ± 0.0	7.4 ± 0.5	7.5 ± 0.3	7.0 ± 0.2
Common Carp				
Density (fish/m^2)	0	1000	2000	3000
Total No.	0	80	160	240
Mean Weight (g/fish)	439.7 ± 8.8	-	461.7 ± 30.2	470.0 ± 22.9
Total Weight (kg/pond)	-	36.9 ± 2.4	75.2 ± 3.6	105.5 ± 2.2
HARVEST				
Tilapia				
Total No.	1433 ± 58	1444 ± 22	1142 ± 199	1536 ± 33
Survival	89.6 ± 3.6	90.3 ± 1.4	71.4 ± 12.4	96.0 ± 2.0
Mean Weight (g/fish)	140.4 ± 10.1	142.6 ± 9.4	148.3 ± 8.6	143.9 ± 15.9
Total Weight (kg/pond)	203.0 ± 5.8	214.3 ± 13.6	170.5 ± 44.4	214.7 ± 16.5
Common Carp				
Total No.	0	58 ± 18	124 ± 31	151 ± 57
Survival	-	75.1 ± 22.3	77.3 ± 19.6	63.1 ± 23.7
Mean Weight (g/fish)	330.3 ± 1.2	-	353.4 ± 35.6	326.4 ± 29.7
Total Weight (kg/pond)	-	20.8 ± 7.3	40.8 ± 11.6	51.6 ± 3.8
Net Yield (t/ha/crop) (Tilapia + Common Carp)	1.92 ± 0.73	2.41 ± 0.07	2.39 ± 0.23	1.61 ± 0.66
REPRODUCTION				
Tilapia				
Total No.	3215 ± 3208	0	50 ± 44	87 ± 69
Survival	72.4 ± 68.0	14.5 ± 9.9	-	19.6 ± 15.4
Mean Weight (g/fish)	32.7 ± 32.4	-	0.6 ± 0.4	3.2 ± 2.2
Common Carp				
Total No.	0	573 ± 164	106 ± 47	506 ± 41
Survival	23.5 ± 4.8	-	28.4 ± 9.5	24.2 ± 5.7
Mean Weight (g/fish)	-	14.5 ± 3.3	3.0 ± 1.4	11.5 ± 1.6

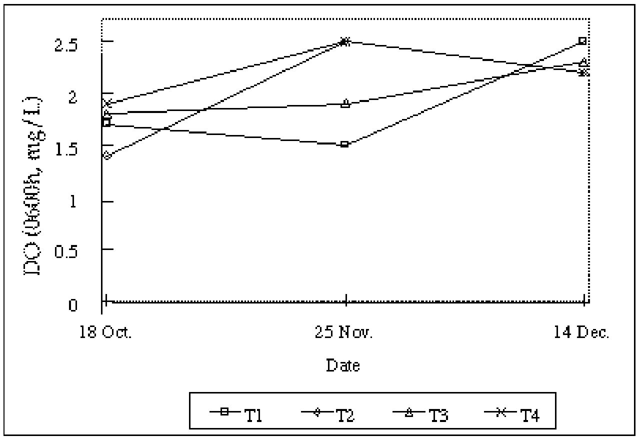

Figure 7. Mean dissolved oxygen (DO) concentration (mg/l) at 0600 h measured at different dates in different treatments.

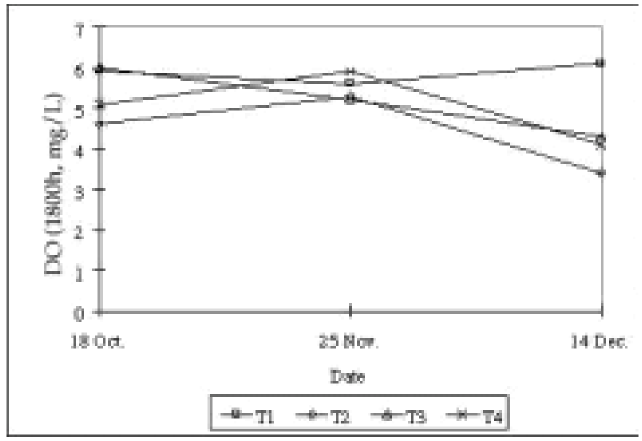

Figure 8. Mean dissolved oxygen (DO) concentration (mg/l) at 1800 h measured at different dates in different treatments.

in such types of pond. Moreover, fish such as common carp, which forage in bottom sediment for food, may facilitate mixing of hypolimnetic water and increase fish production utilizing under-utilized resources when cultured with plankton-feeding fish. However, experimental results did not show differences in net fish yield between the monoculture of Nile tilapia and polyculture with common carp in different densities. Results clearly showed that in all polycultured ponds, common carp lost weight during the experimental period. The loss of weight of common carp in deep ponds might have occurred due to an undesirable feeding environment. Common carp is a bottom-feeding fish and needs to forage in the pond sediment. Accumulation of organic matter in the bottom of deep ponds can lead to oxygen deficit and to the production of reduced substances, e.g., nitrite, ammonia, hydrogen sulfide, and methane (Boyd, 1992), which are toxic to benthic organisms (Clifford, 1992). Anaerobic conditions in pond bottoms are undesirable (Avnimelech and Zohar, 1986) because common carp may have to avoid their feeding ground, therefore resulting in an underfed condition and weight loss. The experiment could not monitor the DO differential between monoculture and polyculture of Nile tilapia with common carp as stated by Szyper (1995).

Acknowledgments

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Literature Cited

Avnimelech, Y. and G. Zohar, 1986. The effect of local anaerobic condition on growth retardation in aquaculture systems. Aquaculture, 58:167-174.

Boyd, C.E., 1992. Shrimp pond bottom soil and sediment management. In J. Wyban (Editor), Proceedings of the Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, LA, USA.

Clifford, H.C., 1992. Marine shrimp pond management: A review. In: J. Wyban (Editor), Proceedings of the Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, LA, USA.

Szyper, J.P., 1995. Diel cycles of temperature and dissolved oxygen stratification in deep rain-fed ponds. In: H.S. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 126-130.

Szyper, J.P. and C.K. Lin, 1990. Techniques for assessment of stratification and effects of mechanical mixing in tropical fish ponds. Aquacultural Engineering, 9:151-165.

Carp/Tilapia Polyculture on Acid-Sulfate Soils

Work Plan 7, Thailand Study 5

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Introduction

PD/A CRSP research in Thailand has concentrated on the dynamics of *Oreochromis niloticus* monocultures. Because *O. niloticus* is primarily a planktivore, the addition of the benthic detritivore *Cyprinus carpio* should lead to increased system productivity through the conversion of currently unutilized benthic matter into fish flesh. The inclusion of carp in the culture system may also increase the recycling rate of nutrients by resuspension of settled organic matter as a result of the stirring activities of the carp (Hopkins and Cruz, 1982). Costa-Pierce and Pullin (1989) suggested that bottom stirring can increase fish production in ponds. This stirring activity may also affect stratification, particularly in deep ponds. The preceding companion study examines carp/tilapia polycultures in deep ponds in Northeast Thailand (p. 157).

Although adding carp to a tilapia monoculture has the potential to increase yields, it may also have the potential to seriously decrease yields if the pond has acid-sulfate soils. Carp could suspend acidic soil into the water column, thereby leading to decreases in alkalinity and subsequent carbon limitation. Also, suspension of muds high in aluminum and iron could, under acidic conditions, lead to removal of phosphorus from the water column. Both carbon and phosphorus limitation could decrease yields. Therefore, a separate study to examine the effects of polyculture on water quality and yield in ponds with acid soils is necessary.

This study's objective was to determine the effects of adding common carp to tilapia culture on the following: fish production; nutrient dynamics including concentration of nitrogen, phosphorus, and carbon (alkalinity); turbidity; and primary productivity.

Materials and Methods

A five-month experiment was conducted in earthen ponds of 200 m^2 surface area at the Asian Institute of Technology. Fifteen ponds were allocated to five treatments with three replicates, in three blocks: block 1 was stocked with common carp juveniles of the smallest of three sizes, namely 11 to 14 g/fish; block 2 was stocked with carp of 23 to 30 g/fish; and block 3 with carp of 35 to 40 g/fish.

The treatments were:

- Tilapia only, stocked as fingerlings of 15-19 g/fish at 2 fish/m^2;
- Tilapia at 2 fish/m^2 plus common carp at 0.1 fish/m^2;
- Tilapia at 2 fish/m^2 plus common carp at 0.3 fish/m^2;
- Tilapia at 2 fish/m^2 plus common carp at 0.5 fish/m^2; and
- Tilapia at 2 fish/m^2 plus common carp at 0.7 fish/m^2.

The ponds were fertilized weekly with chicken manure at 250 kg dry matter/ha/wk and supplemented with urea and triple super phosphate (TSP) to attain rates of 28 kg N/ha/wk and 7 kg P/ha/wk. Water sampling and analysis were performed according to standard protocols, with detailed water sampling/analyses conducted every two weeks.

Results and Discussion

Only preliminary results are available for this experiment. It was noticed during the experiment that tilapia growth was slow and uniform across blocks and treatments. Investigation of the fingerling batch records showed that larger fish (> 25 g/fish) had been selected from the batch to stock a different experiment before this experiment was stocked. This may have left the naturally slower-growing fish, which are unable to grow at normal rates in the fertilized ponds and may have thus obscured treatment effects.

Carp growth was extremely sensitive and inversely related to stocking density, as shown in Figure 1. Reproduction of carp took place in most ponds; these fish were excluded from the growth analysis discussed here. Carp of initial (pond mean) weights 11 to 40 g/fish grew to pond means of 41 to 270 g/fish during five months. There was considerable "growth compensation" (tendency for carp in ponds within a treatment to become more uniform in size) in percentage terms, particularly in the two greatest densities, as would be expected with density-limiting growth.

Through the first half of the experiment, there was little indication of treatment-related differences in water quality except in measures of turbidity.

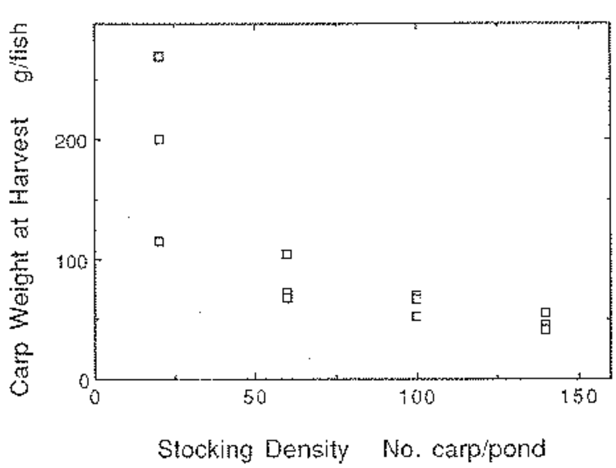

Figure 1. Final individual weight (pond means) of carp in ponds stocked at four different densities.

Secchi depth was slightly greater in ponds without carp; total suspended solids were markedly lower, with mid-point date values of 117 mg/l without carp and 175 to 201 mg/l with carp. Volatile solids did not differ significantly, implying that the difference in total suspended solids (TSS) is attributable to non-volatile or mineral solids (mud). Chlorophyll-*a*, representing food production in the pond ecosystems, did not differ significantly among treatments at the mid point.

Although chlorophyll-*a* levels were not particularly high (99-160 µg/l), they should have been sufficient to produce better growth of tilapia than was observed. Therefore, the batch-selection problem remains the most likely explanation for lack of treatment differences. The larger fish from this batch grew normally in ponds in an experiment in which they were fed.

The parameters chosen for this experiment were appropriate to produce treatment-related differences in suspended solids and to reveal the density dependence of carp growth. Suspended solids tended slightly upward with increased carp density and total biomass of a pond (not individual size) in this experiment, indicating that numbers or biomass were more important than individual size for this factor.

Acknowledgments

We appreciate the collaboration with the University of Michigan, the Royal Thai Dept. of Fisheries, and the Asian Institute of Technology in PD/A CRSP endeavors. Thanks are due to the AIT Aquaculture Laboratory for technical support, and to Messrs. Arun Patel and Yang Yi for management and execution of field and laboratory work and data handling.

Literature Cited

Costa-Pierce, B.A., and R.S.V. Pullin, 1989. Stirring ponds as a possible means of increasing aquaculture production. NAGA, the ICLARM Quarterly, 2:5-7.

Hopkins, K.D., and E.M. Cruz, 1982. The ICLARM-CLSU Integrated Animal-Fish Farming Project: Final Report. Freshwater Aquaculture Center, Central Luzon State University and ICLARM, Manila, Philippines, 96 pp.

On-Farm Production Trials with Nile Tilapia in Fertilized Ponds in Highland and Lowland Areas of the Philippines

Interim Work Plan, Philippines Studies 1 and 3

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Introduction

Production of particle-feeding fishes, such as the now commonly-cultured Nile tilapia (*Oreochromis niloticus*) in fertilized ponds has been reasonably well-researched and demonstrated in technical terms. Actual farmer practices in developing countries, and their amenability to modification by research-derived fertilization guidelines, have been documented and analyzed (Molnar et al., 1994). In general, use of new guidelines requires little modification of basic practices, involving, rather, use of different materials as inputs and reliable and quantitative attention to input schedules and pond appearance. The potential benefits include greatly increased yields per unit pond area and per unit input cost.

On-farm trials of such guidelines have been conducted in several countries by component projects of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP), including those based in Thailand, Honduras, and Rwanda. In the Philippines, small-scale farmers commonly have more than one pond, and grow two crops per year of Nile tilapia using inputs including manure and inorganic fertilizers. The PD/A CRSP guidelines represent, as noted above, only small modification of the routine practices (Molnar et al., 1994).

We report here the results of three trials, each conducted during a coherent production period of four to six months on Luzon island in the Philippines. Two of the trials took place in lowland areas of Central Luzon, Nueva Ecija province; the third was conducted at elevations of 1000 to 1700 m in Mountain province. The objectives of the lowland trials were to demonstrate on-farm feasibility of fertilization guidelines and to quantify yield parameters. The objective of the high-elevation trial was to complete the examination of high-elevation (mainly temperature) effects on farm outcomes which was begun in Rwanda (Seim et al., 1993), but left incomplete by the tragic upheavals there. This trial compared outcomes at different stocking densities at two ranges of elevation.

Table 1. Structure of on-farm production trials for *Oreochromis niloticus* in fertilized ponds in Central and Northern Luzon, Philippines.

Characteristic	Mountain Province		Nueva Ecija Province	
	Barlig Town	*Sagada Town*	*Various Towns*	*Lupao Town*
Elevation (m)	1000 to 1400	1400 to 1700	0 to 100	0 to 100
Period	Mar to Jul	Mar to Jul	Aug to Feb	Oct to Feb
Number of Farms	20	13	11	10
Pond Sizes (m^2)	25 to 136	25 to 200	976 to 5865	135 to 1000
Stocking Density (no./m^2)	1, 2, or 3	1,2, or 3	2	2 or 2.19
Nitrogen Inputs (kg N/ha/d)*	4	4	4	2 or 4

* N:P ratio of nutrient inputs = 5.

Materials and Methods

Three field trials were conducted between March 1994 and February 1996. Farmers were enlisted from Mountain province, a highland region, and the lowland Nueva Ecija province, to manage one of their ponds through one growout cycle of Nile tilapia (*Oreochromis niloticus*) using specified stocking and fertilization protocols. Fingerlings were grown to market size, taking approximately four months in most cases. The highland region consisted of two elevation ranges, 1000 m to 1400 m above MSL, and 1400 m to 1700 m.

Fingerling *O. niloticus* of approximate weight 4 g/fish for initial stocking, and fertilizers for weekly addition to ponds, were given to the farmers; sampling of fish and water was done monthly by the senior author and local project personnel, who also assisted farmers with the initial fertilizer application. Cost-free provision of fingerlings was considered a necessary incentive in these early trials because the local costs are significant, approximately $0.005 to $0.020 depending on size, although some communal ponds may receive free stock from government hatcheries.

Table 1 details the structure of these trials in terms of location, numbers of participants, and intended comparisons of parameters, including elevation ranges (1000 m-1400 m and 1400 m-1700 m), different stocking densities (1, 2, and 3 fish/m^2) in the high-elevation trial and two levels of fertilizer input (4 and 2 kg nitrogen/ha/d, at an N:P ratio of 5:1, as diammonium phosphate and urea) in one of the low-elevation trials. The higher fertilization rate was standard for the other trials. The other low-elevation trial involved several different strains of *O. niloticus*, but was not designed as a formal comparison.

Monthly sampling and analyses consisted of:

1) sampling of at least 25 fish, randomly selected from a seine haul, for total length (TL) and bulk weight;
2) near-surface water samples for analysis of total alkalinity (TA), total ammonia, soluble reactive phosphorus (SRP), pH, dissolved oxygen (DO) and temperature; and
3) measurement of pond depth.

In addition, in the second lowland trial DO and temperature were measured at top, middle, and bottom depths when possible, and Secchi disc depths were recorded.

Ponds were harvested after approximately four months (longer in some cases) by seining and complete draining. Fish were weighed and measured as above and left to the farmers, who consumed, bartered, or re-stocked them for further growout.

Water analyses were performed according to standard protocols (Lind, 1974; Boyd 1979). Dissolved oxygen was measured in the field by polarographic probe; pH was determined in the laboratory by gel-filled combination electrode; total ammonia was determined by the indophenol method; total alkalinity was determined by titration to the methyl orange end point; and

Table 2. Tilapia yields (kg/ha/yr) from on-farm fertilization trials.

Characteristic	Mountain Province		Nueva Ecija Province	
	Barlig Town	*Sagada Town*	*Various Towns*	*Lupao Town*
Elevation (m)	1000 to 1400	1400 to 1700	0 to 100	0 to 100
Number of Farms	20	11	11	8
Average Yield	1259	2215	2309	2217
Minimum Yield	538	981	859	1109
Maximum Yield	2195	3524	3293	3920

Note: The two farms using feeds had yields of 9356 and 10,933 kg/ha/yr.

soluble reactive phosphorus (SRP) was determined by the molybdate method. Statistical analyses were performed using Statmost and Cricket Graph.

Results and Discussion

Data were collected from 52 of the 54 farms stocked. The other two ponds were lost to a dike collapse and poaching. Fifty of the farms reported that they had used the PD/A CRSP fertilizer regime. Two of the farms used feed instead.

Extrapolated fish yields were extremely variable and ranged from 538 to 3920 kg/ha/yr (Table 2). The yields from Barlig town in Nueva Ecija had lower yields than either Sagada or the lowland ponds. It appears that this is related to survival. In Barlig, 60% of the farms had survival of less than 51%. In Sagada, only 18% of the farms had such poor survival.

A direct examination of the effects of stocking density on yields was impossible because of the variability in survival rates. As most mortality occurs early in an experiment, harvest density was used as an indicator of fish density during the experiment. Fish density accounted for 69% of the variability in yields (Figure 1). The reasons for the variability in density have not yet been identified, but could be attributed to a range of factors from stocking stress to poaching.

Comparison of the lowland trials to the highland trials was complicated not just by variable survival, but by the seasons as well. Given the availability of project facilities and staff, it was impossible to conduct the trials simultaneously. The highland trials started in early spring and ran into the summer. The lowland trials started in late summer and ran into the winter. Low water temperatures, slightly below 20°C, were measured in both the highlands and lowlands. However, based on reliable information, winter temperatures in the highlands can be much lower than this. Thus, our extrapolation of yields to an annual basis is probably invalid for the highlands. Although multiple crops per year are possible in lowland areas, probably only a single tilapia crop per year is possible in the Mountain Province.

Literature Cited

Boyd, C.E., 1979. Water Quality in Warmwater Fish Ponds. Agricultural Experiment Station, Auburn University, Alabama, 359 pp.

Lind, O.T., 1974. Handbook of Common Methods in Limnology. C.V. Mosby, St. Louis, 154 pp.

Molnar, J.J., T.R. Hanson, and L.J. Lovshin, 1994. Minding the pond: feeding, fertilization, and stocking practices for tilapia production in Rwanda, Thailand, the Philippines, and Honduras. In: H. Egna, J. Bowman, B. Goetze, and N. Weidner (Editors). Twelfth Annual Technical Report 1994, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 34-46.

Seim, W.K., K.L. Veverica, T.J. Popma, and A. Gatera, 1993. On-farm production of monosex *Oreochromis niloticus* in Rwandan farm ponds at altitudes above 1300 meters. In: H. Egna, J. Bowman, B. Goetze, and N. Weidner (Editors). Eleventh Annual Technical Report 1993, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, USA, pp. 71-79.

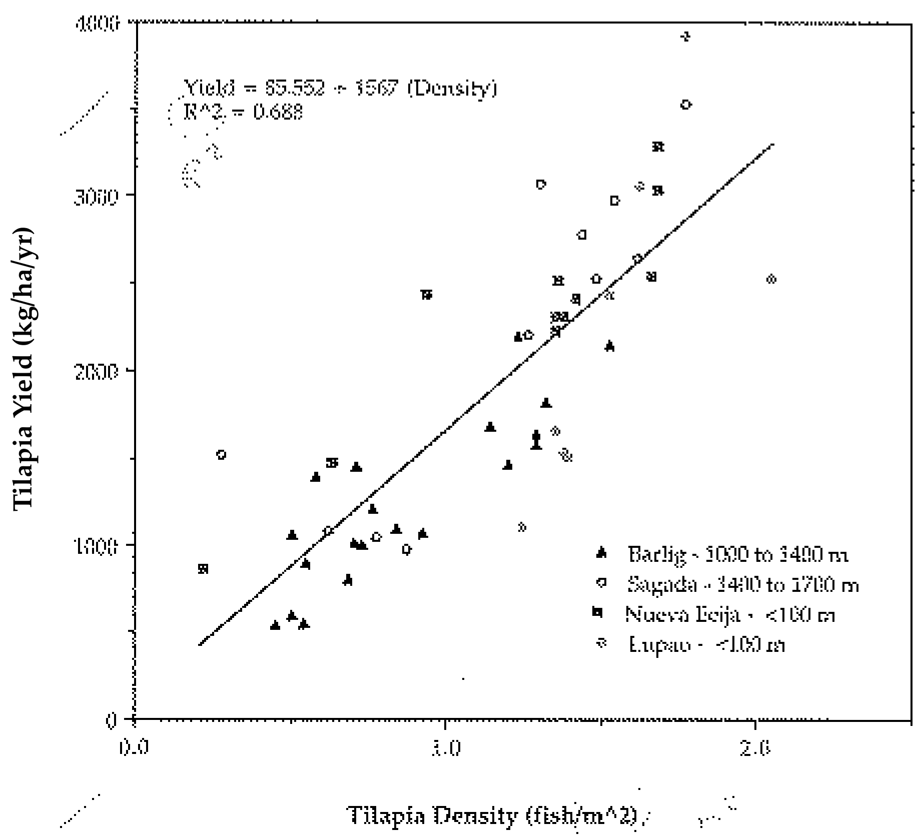

Figure 1. Effects of density on tilapia yields from farms at 3 elevations in the Philippines.

Global Examination of Relationship between Net Primary Production and Fish Yield

Interim Work Plan, Thailand Study 1

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Introduction

PD/A CRSP study of pond ecosystems has focused on primary productivity. This focus was a natural and appropriate consequence of the principle, and some evidence, that photosynthesis, as the source of fixed carbon to the food chain, must be critical to fish production in fertilized ponds. There were earlier efforts by two DAST components which examined productivity from the Central Database, but no recent or fully global syntheses of the relationships. Additionally, several CRSP papers have shown the positive relationship between primary productivity and fish yield within more limited data sets (for example, Knud-Hansen and Batterson, 1994)

The objective of this study was to synthesize and analyze pertinent information contained in the CRSP Central Database on the relationship between primary productivity and fish production.

Materials and Methods

The CRSP Central Database as it existed in late 1995 and early 1996 was used as the source of raw data. Information on fish yields and primary productivity as indicated by photosynthetic oxygen production was available for 505 ponds. Photosynthetic oxygen production for this purpose means the daytime net increase in dissolved oxygen (DO) concentration. This is termed "daytime net primary production (dNPP)" and is, in practical terms, close to the "DO at 1600 hours minus DO at 0600 hours" quantity which is available from the diel sampling regimes. This quantity is integrated through the water column, and over the time intervals during which fish growth is measured. "Production of fish biomass" or Net Fish Yield (NFY) means the net increment in total weight of the stock in a pond during a given period, in this case, excluding the weight of fry produced after stocking.

Analysis consisted of computation of frequency distributions and curve-fitting using Excel and Cricket Graph.

Results and Discussion

Analysis began with 505 ponds from PD/A CRSP experiments reported to the Database, for which data on primary production and fish yield could be rationalized and averaged for the entire experimental period, generally about 150 days. There is a strong central tendency to dNPP values, with most ponds producing 2 to 8 mg/l DO during daylight periods (Figure 1). The range of values (0-14) is large enough to be amenable to large scale regression and correlation analyses.

Daytime net production of DO and fish yield are strongly related (Figure 2). The exponential equation presented (other relationships will be examined in future papers) accounts for 62 percent of the observed variation in fish yields over the 505 ponds. It is certain that this relationship differs among individual experiments, and highly likely that it differs for various subsets of the data, such as season, site, environmental conditions, and various aspects of fertilization regime. The "complete" analytical task can now be seen to be large, and limited mainly by the pertinence and prioritization of questions to be asked.

The increased variation in fish yields at higher levels of dNPP is a natural consequence of the "resource limitation" phenomenon, in which the process or product of interest (fish biomass) is closely dependent on the resource (dNPP: oxygen, carbon, etc.) when the resource is in short supply, but is determined by other factors (not analyzed

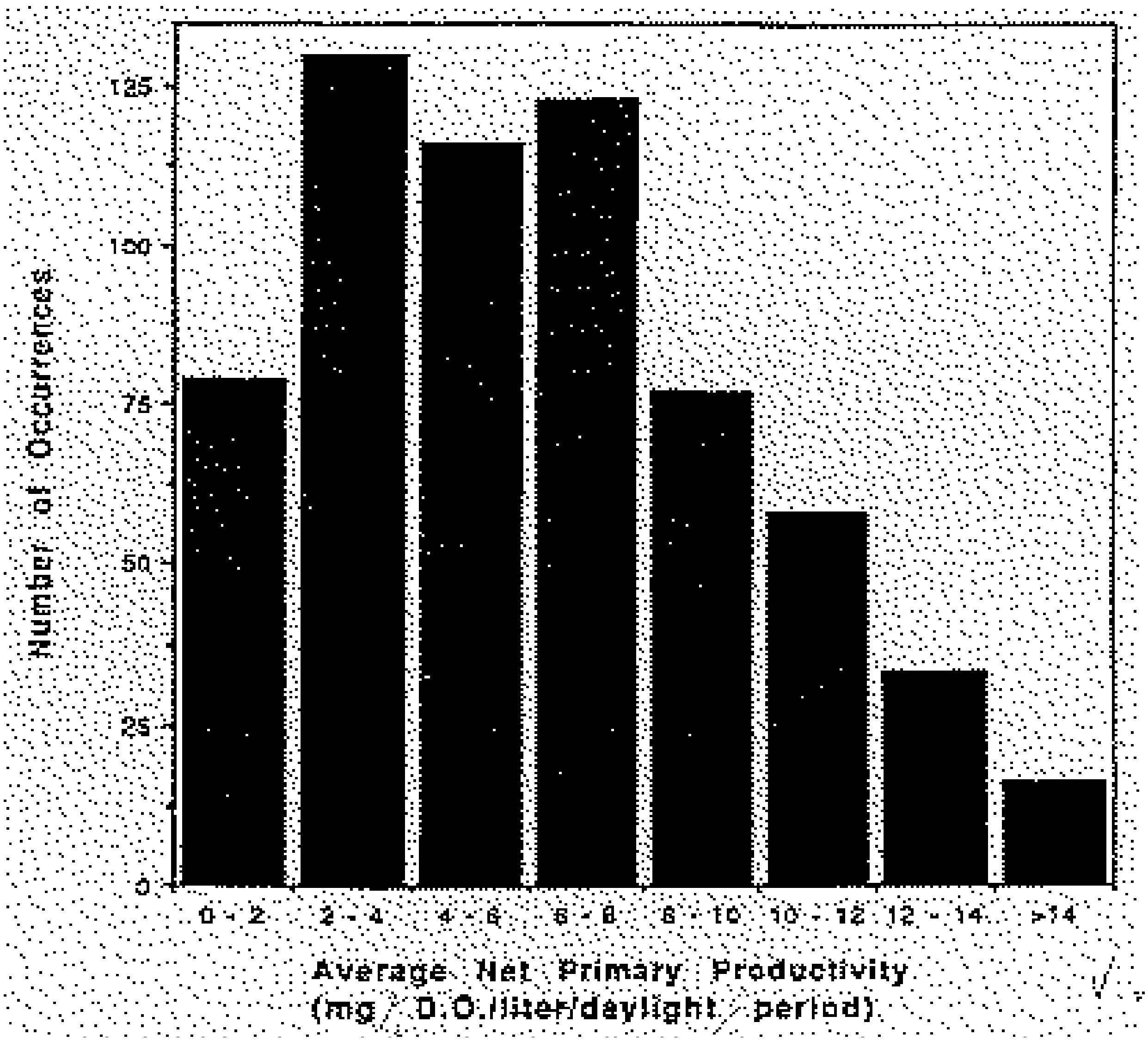

Figure 1. Frequency of average NPP extracted from the CRSP Central DataBase. Each occurrence is the average NPP for a pond during an experiment.

here) when the resource is more abundant. This data set thus provides a guide to the levels of dNPP which are likely limiting to fish production (below 10 mg/l DO during daylight). This guide will be particularly valuable for selecting subsets of the data for further analysis.

Literature Cited

Knud-Hansen, C.F. and T.R. Batterson, 1994. Effect of fertilization frequency on the production of Nile tilapia (*Oreochromis niloticus*). Aquaculture, 123:271-280.

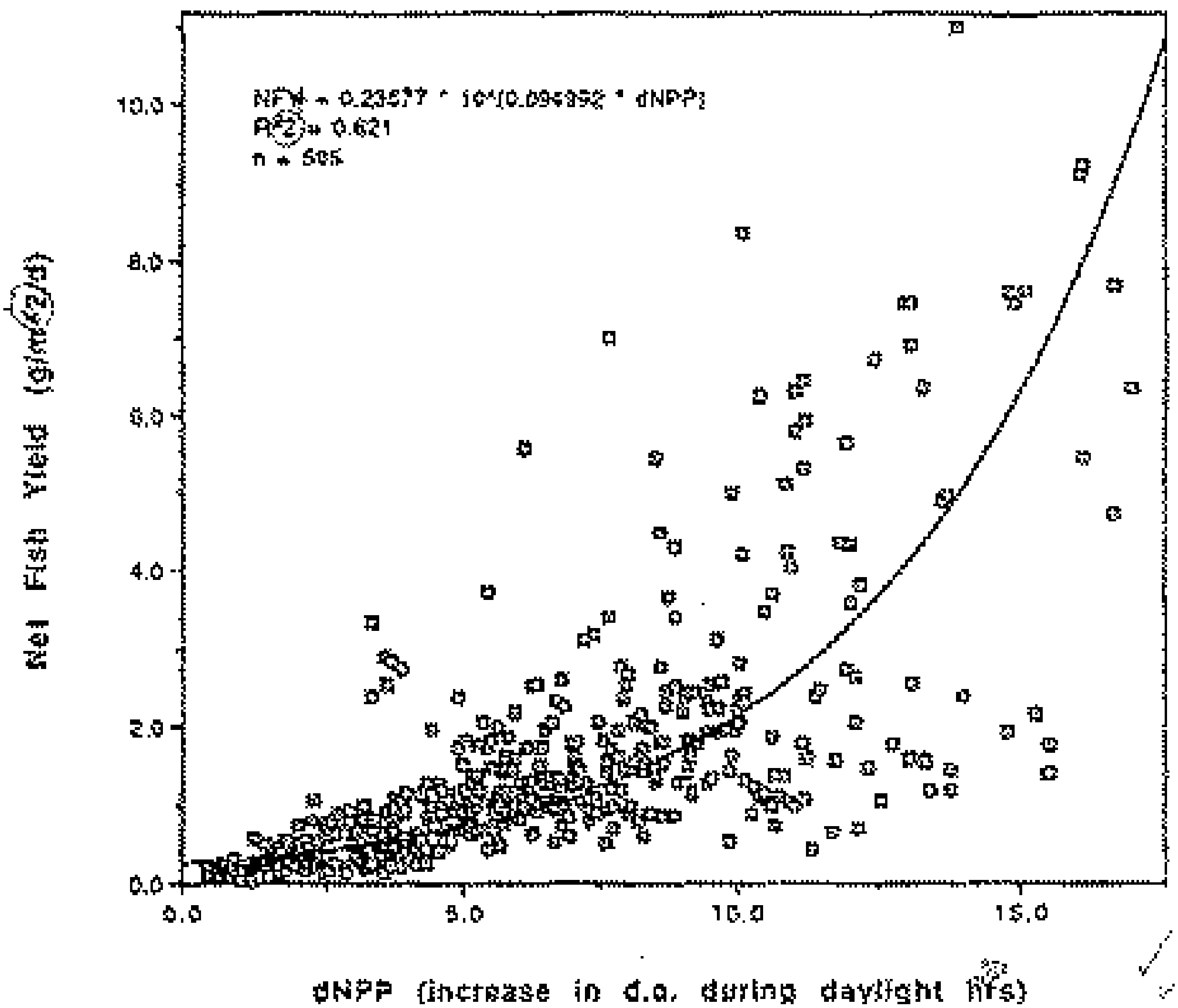

Figure 2. Relationship of fish yield and net primary productivity.

Data Analysis and Synthesis

DAST researchers at the University of California, Davis (UCD) continued refining models reported in previous annual reports. An aquaculture pond model useful for the analysis of integrated aquaculture-agriculture systems was modified, and changes were made to a model designed to simulate water temperature, dissolved oxygen (DO), and fish growth in stratified fish culture ponds.

The accuracy of model simulations of organic matter, nitrogen, and fish production in ponds is important for the analysis of integrated aquaculture-agricultural systems. Fishpond ecosystem models have not specifically included organic matter dynamics—processes occurring in the water column and sediments of fish ponds—as primary components of the system. In order to refine organic matter dynamics in fish ponds, DAST researchers began modification of two submodels, a bioenergetic and a multi-G model, which are part of an integrated aquaculture-agriculture model.

The bioenergetic model, which simulates fish growth, was modified to include the effect of feed quality and different digestibility coefficients for various feed types. Preliminary results pertaining to fish growth, nitrogen, and organic matter accumulation are described in this year's report. Fish growth rate simulated by the modified equation was similar to observed data from a PD/A CRSP site in Butare, Rwanda. This result is promising, and after further development and testing, researchers anticipate that the model will be a useful tool for the study of aquaculture systems models where agricultural wastes are the primary feed input sources.

The multi-G model was used to simulate water column and sediment organic matter. Sediment and water column organic matter concentration values were similar to values reported for agriculture waste-fed ponds. Water column nitrate also followed a trend similar to data collected from the PD/A CRSP site in Butare, Rwanda; however, other nitrogen parameters (i.e., sediment nitrogen) require further refinement.

To better predict the variability of water quality and fish growth associated with weather conditions at a given location, further modifications were made to a model of water temperature, dissolved oxygen (DO), and fish growth for stratified fish culture ponds by adjusting the procedure for generating daily and hourly solar radiation estimates. Simulation of hourly results were verified using PD/A CRSP data collected in Thailand. Cumulative probability distributions of daily solar radiation values generated by the model compared well with data measured in Thailand. Temperatures simulated at three depths—the surface, middle, and bottom layers—did not always correspond to the measured data; differences between measured and simulated values were more pronounced for the surface water layer than for the middle and bottom layers. Comparisons of DO values for the three water layers were in agreement—most of the measured values fell within the range of simulated values. Although limited fish growth data are available, measured values of growth fell within the range of simulated values. The difference between maximum and minimum simulated values increased with time, indicating that the width of the probability distribution of the size of the harvested fish increased with time.

The modified solar radiation sub-model proved effective for the estimation of solar radiation values with limited data sets. Further, the temperature, DO, and fish growth simulation results corresponded with measured values, even for long-term simulations.

Through the practical application of POND© decision support software, PD/A CRSP researchers at Oregon State University continued to generate information for pond aquaculture planning and management. A water budget model that considers various sources and sinks was used to predict water requirements for CRSP sites in Thailand and Honduras. Feed requirements for aquaculture ponds were also assessed through the use of the POND© bioenergetics (BE) model. Simulations of plankton biomass changes in Nile tilapia ponds were also undertaken using more complex POND© models. POND© heat balance and fish growth models also were used to conduct sensitivity analyses. Accurate estimations are achievable via a combination of field experimentation and appropriate use of the POND© parameter estimation package.

In a separate effort, OSU DAST team members—in collaboration with the FAO Inland Water Resources and Aquaculture Service—estimated fish yield in Latin America as part of FAO's effort to assess aquaculture potential through the use of a geographical information system (GIS). The POND© heat balance model was used to generate water temperature profiles for continental Latin America. Water temperature profiles were then used in the POND© fish growth model together with pre-set satiation feeding levels and harvest sizes to assess the number of crops per year possible under commercial scale aquaculture for four fish species: Nile tilapia (*Oreochromis niloticus*), tambaquí (*Colossoma macropomum*), pacu (*Piaractus mesopotamicus*), and common carp (*Cyprinus carpio*). The potential for small-scale and subsistence aquaculture was also evaluated.

Application of POND© as a Tool for Analysis and Planning and *Applications of Heat Balance and Fish Growth Models for Continental-Scale Assessment of Aquaculture Potential in Latin America* are contained in the Global Studies and Activities section of this publication.

Aquaculture Pond Modeling for the Analysis of Integrated Aquaculture/Agriculture Systems: Fishpond Organic Matter and Nitrogen Dynamics

Interim Work Plan, DAST Study 5

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Introduction

The development of models which allow for accurate simulation of organic matter, nitrogen, and fish production in ponds is important for analyzing the integration of aquaculture and agricultural systems. While various fishpond ecosystem models exist, they do not specifically include organic matter dynamics as primary components of the system. However, a majority of processes occurring in the water column and sediments of fishponds are related to the transformations of organic matter.

Current methods used to simulate organic matter dynamics and fish growth may be inadequate for models that specifically include organic matter processes in fish ponds (Jamu and Piedrahita, 1995; Munsiri and Boyd, 1995). Preliminary results reported by Jamu and Piedrahita (1995) showed that fish growth models need to be modified to include the effects of feed quality and differences in feed digestibility if the models are to accurately simulate organic matter transformations in fish ponds. This is especially true for pond management systems that utilize non-conventional feed and fertilizer sources. Munsiri and Boyd (1995) showed that, with the use of a single first-order rate constant to model organic matter degradation, equilibrium conditions were reached in a relatively short time, and organic matter accumulation rates were overestimated. The inadequacy of such an approach has also been recognized in marine sediment models. For example, Jorgensen (1979) recommended that organic matter be divided into different groups of compounds of different reactivity, each undergoing first-order decomposition. This report describes the modifications made to the modeling of organic matter dynamics in fishponds and presents preliminary results for fish growth rates, nitrogen, and organic matter accumulation obtained by the modified models.

Model Structure

The organic matter and nitrogen processes are components of the water quality and sediment submodels of the integrated aquaculture-agriculture model whose general framework was reported by Jamu and Piedrahita (1995). Details of each of the two sets of processes are described below.

Organic Matter Degradation

The simulation of organic matter degradation and accumulation rates is based on the multi-G model of Westrich and Berner (1984) which, after considering effect of temperature and media C/N ratio on the decomposition rate constant, can be expressed as:

$$\frac{dG_i}{dt} = -k_i \cdot G_i \cdot M_{CN} \cdot \tau \qquad (1)$$

$$-\frac{dG_{tm}}{dt} = \sum_{i=1}^{n} k_i \cdot G_i \cdot M_{CN} \cdot \tau \qquad (2)$$

$$G_{tm} = \sum_{i=1}^{n} G_i \qquad (3)$$

where,

G_i = concentration of organic matter in each organic matter group (kg ha^{-1});

G_{tm} = the total concentration of organic matter (kg ha^{-1});

t = time (d);

k_i = decay rate constant of each organic matter group (d^{-1});

t = temperature parameter (0 to 1); and

M_{CN} = carbon to nitrogen ratio parameter for organic matter group (0 to 1).

In this model, organic matter is grouped under three categories: (a) stable organic matter, (b) moderately decomposable organic matter, and (c) easily decomposable organic matter. Stable organic matter is defined as the organic matter which has undergone decomposition at least once (van Keulen and Seligman, 1987). The easily decomposable organic matter is made up of readily metabolizable subgroups of organic matter. In the current model, this group consists of carbohydrates and proteins. The moderately decomposable organic matter subgroup is made up of cellulose and lignin. These subgroups and stable organic matter are then used in the implementation of the model, and each has its own decay rate constant depending on its reactivity. The reactivities of the three subgroups and of stable organic matter are shown below in decreasing order. The values indicated in parenthesis are typical rates reported for the various groups (van Keulen and Seligman, 1987):

carbohydrates and proteins (0.8 d^{-1})
>> cellulose (0.05 d^{-1})
>> lignin (0.0095 d^{-1})
>> stable organic matter (8.3 x 10^{-5} d^{-1}) (4)

This decreasing reactivity order is reflected in decreasing values for the decay rate constants for the various organic matter groups. Mass balance calculations can be carried out for each of the organic matter groups using the corresponding decay rate coefficients and information on the composition of various organic matter sources in a pond (Figure 1). The concentrations of different groups or fractions of organic matter are determined from proximate analyses for different food or fertilizer types being applied to a fishpond. Proximate analyses and decay rate coefficients for different feed and fertilizer types are available from the literature (e.g. Gohl, 1981). The modified fish growth simulation model has been reported previously (Figure 1) (Jamu and Piedrahita, 1995).

While the simulation of organic matter transformations in the water column is relatively straightforward, the sediment component is complicated because of the existence of aerobic and anaerobic layers. For simplicity, the model has been designed to recognize two sediment layers only. First there is an upper 1-mm layer (Blackburn, 1990), with a dynamic oxygen concentration based on the oxygen concentration existing in the overlaying water; the second layer is the sediment beyond the first millimeter, which is considered to be anaerobic and homogenous with respect to sediment porosity and organic matter distribution. Whereas it is recognized that sediments will in fact be stratified within the anaerobic layer, this simplifying assumption is considered necessary at this point, given the information available on pond sediments and the relative biochemical activity at various depths.

$$\text{Diffusion rate} = (\text{Porosity}) \cdot (\text{Diffusion coefficient}) \cdot \frac{(\text{Concentration difference})}{\text{Depth}}$$

where,

Diffusion rate = diffusion rate for nitrogen species (kg $m^{-2}d^{-1}$);

Porosity = void volume fraction (dimensionless);

Diffusion coefficient = diffusion coefficient (m^2 d^{-1});

Concentration difference = difference in concentration between water and sediments (kg m^{-3}); and

Depth = sediment depth (m) (5)

Nitrogen Transformations

Nitrogen transformations for each organic matter group are simulated using first order models adopted in other fishpond ecosystem models (Piedrahita, 1990; Kochba et al., 1994). In addition, the nitrogen model includes a diffusion term for nitrate-nitrogen (NO_3^--N) and total ammonia nitrogen (TAN) between the water column and sediment. The diffusion of TAN and NO_3^--N is obtained from (Blackburn and Blackburn, 1992) (see above).

The sediment nitrogen component also includes adsorption of TAN by the sediments. The amount of TAN adsorbed is determined by a potential upper limit for TAN adsorption calculated from sediment cation exchange capacity (CEC) values (Mehrani and Tanji, 1974). The potential upper limit for TAN adsorption calculated from CEC values is only approximate, since not all exchange sites in the sediment are occupied by TAN as other cations compete for the exchange sites. In the model it is

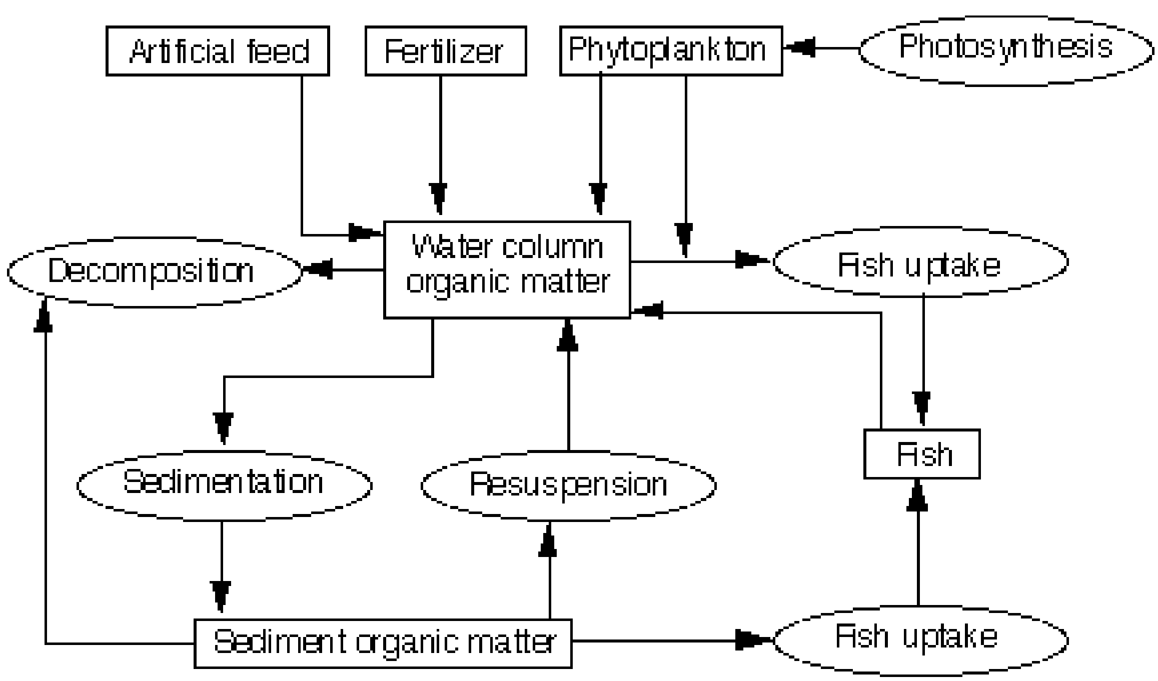

Figure 1. Schematic diagram of the sources and sinks for organic matter in the water column and in the sediment of an aquaculture pond.

$$\mathrm{TANadsorption} = (\mathrm{PorewaterTAN}) \cdot (\mathrm{SpecificTANadsorption}) \cdot (\mathrm{AdsorbedTAN})$$

where,

TANadsorption = Rate of TAN adsorption by the sediments (kg TAN ha-1 d-1)

PorewaterTAN = TAN in the pore water (kg ha-1)

SpecificTANadsorption = Specific rate of TAN adsorption (d-1)

AdsorbedTAN = Fraction of TAN adsorbed (Dimensionless) (6)

assumed that TAN adsorption will only occur when the potential upper limit for TAN adsorption is greater than the TAN adsorbed by the sediment; i.e., when the exchange sites are not completely occupied by TAN. The TAN adsorption rate is defined as the rate at which pore water TAN is attracted to the sediment through physical and chemical processes as well as mass action (Tchobanoglous and Schroeder, 1987). TAN adsorption rate can be obtained from the above equation (Deizman and Mostaghimi, 1991).

Other processes, sources, and sinks that are considered in nitrogen mass balance calculations are shown in Figure 2.

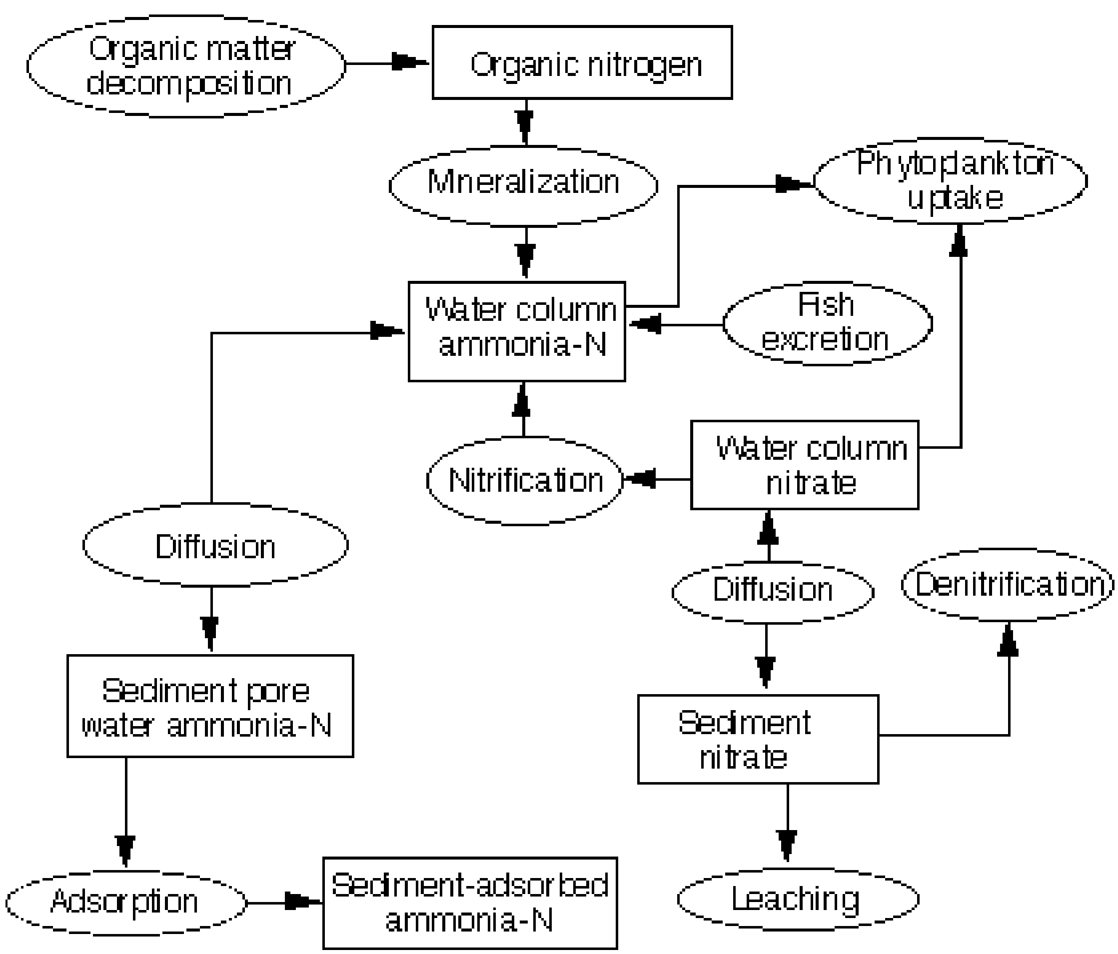

Figure 2. Schematic diagram of the sources and sinks for nitrogen in the water column and in the sediment of an aquaculture pond.

Results and Discussion

The model was run for a period of 145 days using parameter values and constants obtained from the literature. Environmental data and initial conditions for state variables were obtained from data corresponding to the PD/A CRSP Workplan 3 for the Butare, Rwanda site. The values simulated for fish growth, water column nitrate, and sediment nitrogen by the model were compared to observed data for the Rwanda site.

Fish Growth

The simulation of fish growth using a bioenergetic model modified to include the effect of feed quality and different digestibility coefficients for various feed types is shown in Figure 3. The fish growth rate simulated by the modified equation is similar to observed data at the site selected. The modified fish growth model takes into consideration the feed quality and feed digestibility coefficients of artificial feed. The model results are very promising so far, and after further development and testing, the model is expected to be a useful tool in the study of aquaculture systems models where agricultural wastes are the primary feed input sources.

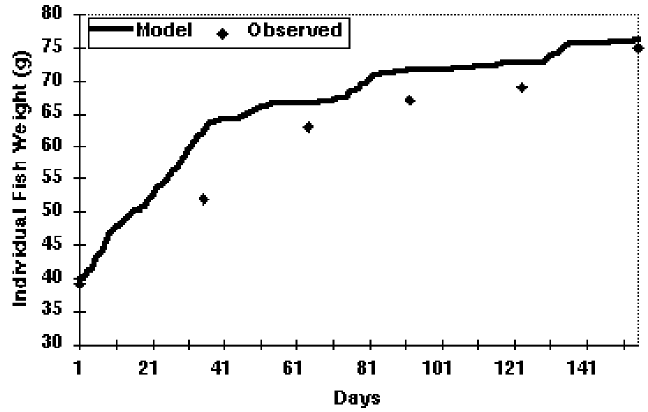

Figure 3. Fish weight predicted by the modified bioenergetics model for the Butare site in Rwanda.

Organic Matter and Nitrogen Dynamics

Simulation results for water column and sediment organic matter using the multi-G model for organic matter degradation are shown in Figure 4 for the same data set used for the fish growth trials. The Rwanda data do not include sediment organic matter production, hence model output cannot be compared to data from this site. However, the final sediment organic matter concentration of 2,620 kg ha^{-1} is similar to values reported for agriculture waste-fed ponds (2,000-2,100 kg ha^{-1}) (Hiwagara and Mitsch, 1994; Jamu, unpublished data). The results for final water column organic matter concentrations (650 kg ha^{-1}) also fall within the range (140-770 kg ha^{-1}) reported for agricultural waste-fed ponds (ICLARM-BMZ/GTZ, in press; Milstein et al., 1995).

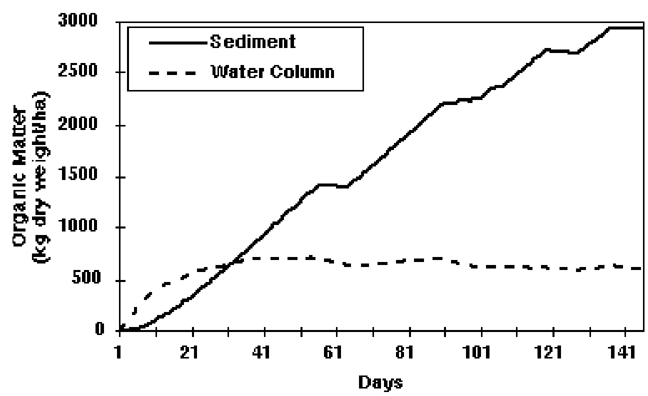

Figure 4. Water column and sediment organic matter predicted using the multi-G organic matter model.

Water column nitrate follows a trend similar to the observed data (Figure 5), but the simulation of other nitrogen parameters need further development. The preliminary results for sediment nitrogen show that the concentration of soil nitrogen (0.14 kg nitrogen/kg sediment organic matter dry weight) obtained in the simulations is much higher than the value observed (0.27 mg nitrogen/kg soil).

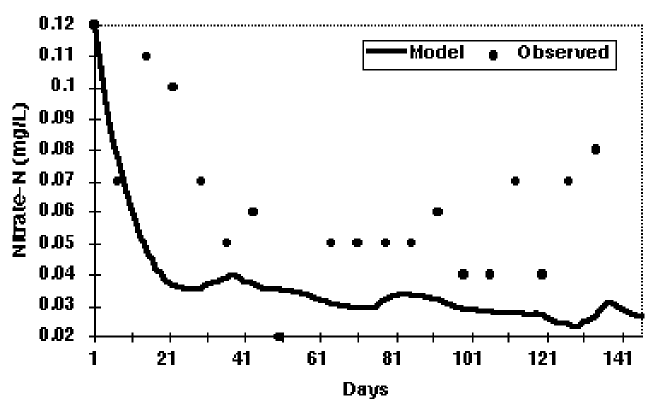

Figure 5. Water column nitrate nitrogen simulation for the Butare site in Rwanda.

However, the model sediment nitrogen concentration is based on sediment organic matter only. The average organic matter content for pond soils is 4% (Boyd, 1995), and simulated soil nitrogen values are approximately two orders of magnitude greater than expected. Other nitrogen processes (e.g., diffusion and TAN adsorption) in the sediment are directly linked to the amount and depth of sediments. Information on the extent to which the native pond soil participates in nitrogen processes should improve the simulation of sediment nitrogen processes.

Literature Cited

Blackburn, T.H., 1990. Denitrification model for marine sediments. In: Sorensen, J., and N.P. Revsbech (Editors). Denitrification in Soil and Sediment. Plenum Press, New York, pp. 323-337.

Blackburn, T.H. and N.D. Blackburn, 1992. Model of nitrification and denitrification in marine sediments. FEMS Microbiology Letters, 100:517-522.

Boyd, C.E., 1995. Bottom Soils, Sediment, and Pond Aquaculture. Chapman and Hall, New York, 348 pp.

Deizman, M.M. and S. Mostaghimi, 1991. A model for evaluating the impacts of land application of organic waste on runoff water quality. Research Journal WPFC, 63:17-27.

Gohl, B., 1981. Tropical Feeds: Feed Information Summaries and Nutritive Values. FAO, Rome, 529 pp.

Hiwagara, H. and W.J. Mitsch, 1994. Ecosystem modeling of a multi-species integrated aquaculture pond. Ecological Modeling, 72:41-73.

ICLARM-BMZ/GTZ, in press. The ICLARM-BMZ/GTZ Africa Aquaculture Project: Final Technical Report. International Center for Living Aquatic Resources-Bundesministerium für wirtschaftliche Zusammenarbeit/Deutsche Gesselleschaft für Technische Zusammenarbeit.

Jamu, D.M. and R.H. Piedrahita, 1995. Aquaculture pond modeling for the analysis of integrated aquaculture/agriculture systems. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 142-147.

Jorgensen, B.B., 1979. A comparison of methods for the quantification of bacterial sulfate reduction in coastal marine sediments. II. Calculation from mathematical models. Geomicrobiol. J., 1:29-47.

Kochba, M., S. Diab, and Y. Avnimelech, 1994. Modeling nitrogen transformations in intensively aerated fish ponds. Aquaculture, 120:95-104.

Mehrani, M. and K.K. Tanji, 1974. Computer modeling of nitrogen transformations in soils. J. Environ. Quality, 3:391-396.

Milstein, A., A. Akron, I. Karpus, M. Kochba, and Y. Avnimelech, 1995. Combined effects of fertilization rate, manuring, and feed pellet application on fish performance and water quality in polyculture ponds. Aquaculture Research, 26:55-65.

Munsiri, P. and C.E. Boyd, 1995. Physical and chemical characteristics of bottom soil profiles in ponds at Auburn, Alabama, USA, and a proposed system for describing pond soil horizons. World Aquaculture Society, 26:346-377.

Piedrahita, R.H, 1990. Calibration and validation of TAP, an aquaculture pond water quality model. Aquacultural Engineering, 9:75-96.

Tchobanoglous, G. and E.D. Schroeder, 1987. Water Quality. Addison and Wesley, Massachusetts, 768 pp.

van Keulen, H. and N.G. Seligman, 1987. Simulation of water use, nitrogen nutrition and growth of spring wheat. Pudoc, Wageningen, 310 pp.

Westrich, J.T. and R.A. Berner, 1984. The role of sedimentary organic matter in bacterial sulfate reduction: The G-model tested. Limnol. Oceanogr., 29:236-249.

Modeling of Temperature and Dissolved Oxygen in Stratified Fish Ponds Using Stochastic Input Variables

Interim Work Plan, DAST Study 4

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Introduction

A model is being developed using stochastic input variables for the simulation of temperature, dissolved oxygen (DO), and fish growth in stratified fish ponds. Two major modifications have been made from the previous version of the model during the past year: the procedure for generating daily and hourly solar radiation data was changed; and oxygen consumption by nitrification was separated from the water column respiration term. In the previous model, the procedure for generating solar radiation values was based on the mean and variance of historical data for each day; however, the recorded data available through the PD/A CRSP Central Database have many missing values. This, in part, is due to the fact that weather data were collected only when pond experiments were being conducted. A new statistical method has been used with the data to develop a procedure for generating solar radiation values for stochastic pond simulations. For short term simulations, oxygen consumption rate by nitrification and decomposition of carbonaceous organic matter can normally be combined into a single, temperature dependent term. For the long term simulations (approximately one growing season) currently being carried out, these two oxygen consuming processes need to be considered separately, and the model has been modified to include the two terms.

Model Structure

The model includes sub-models for generation of weather values,simulation of temperature, DO, and fish growth. The temperature and DO sub-models are based on the work of Losordo (1988) and Culberson (1993) and have been modified for long-term simulations as described by Santos Neto and Piedrahita (1995). Additional modifications have been implemented to the dissolved oxygen model regarding phytoplankton simulations (Lu and Piedrahita, 1996). The fish growth model has been described by Jamu and Piedrahita (1996). The new procedure developed for the generation of solar radiation values and the separation of the water column oxygen consumption from nitrification are described in this report.

Model to Generate Solar Radiation Values

The goal of this research is to develop a water quality model which can predict the variability of water quality and fish growth associated with weather conditions at a given location. To achieve this goal, it is essential that the weather parameters used to execute the water quality and fish growth models accurately represent conditions at the chosen site. Conventional methods for generating weather parameters are based on probability distributions generated from long term records for a given site. However, the data available through the PD/A CRSP database do not fulfill the requirements of conventional weather prediction methods; data have not been collected for enough years, and since data were collected only while pond experiments were in progress, many of the years for which data are available are incomplete. The method developed and presented here is based on the monthly groupings of the data.

Previous researchers have found that the monthly cumulative probability distributions of clearness index (clearness index, K_t, is defined as the ratio between solar radiation at a particular site and theoretical, extraterrestrial solar radiation) are independent of location and month (Liu and Jordan, 1963). The monthly cumulative distributions were found to be functions of monthly average clearness

$$K_t(n) = F^{-1}[G(\chi(n))] \quad (1)$$

where,

$F^{-1}[]$ = the inverse function of $F[K_t]$, the cumulative probability function which is obtained from the measured data,

$$G[\chi(n)] = 0.5 + 0.5 * \mathrm{erf}(\chi(n)/\sqrt{2}) \quad (2)$$

$\mathrm{erf}(\chi)$ = error function defined as

$$\mathrm{erf}(\chi) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\chi} \left(e^{-t^2/2}\right) dt \quad (3)$$

$\chi(n)$ = random number generated using a first order autoregressive model

$$\chi(n) = \rho \cdot \chi(n-1) + \omega \quad (4)$$

r = autocorrelation coefficient of lag one between two consecutive days

w = normal distribution random number with a mean of zero and a variance of $1-\rho^2$

$$K_h = K_m - \frac{\sigma_{kt}}{1.58} \ln\left[\frac{1}{0.5(1+\mathrm{erf}(\frac{\varepsilon}{\sqrt{2}}))} - 1\right] \quad (5)$$

where,

K_h = generated hourly solar radiation value at time h

$$K_m = K_i - 1.167K_i^3(1-K_i) + 0.979(1-K_i)\exp[\frac{-1.141(1-K_i)}{K_i \cos\theta_Z}] \quad (6)$$

K_i = generated daily solar radiation value on day i

q_z = zenith angle

$$\sigma_{kt} = 0.1557\sin(\frac{\pi K_i}{0.933})$$

ε = normally distributed random number with a mean of zero and a standard deviation of one.

index, $\overline{K}_t$ (Liu and Jordan, 1963). Because the probability distribution of clearness index values is not normal, it needs to be transformed to a normal distribution so that a random number can be generated and used with the probability distribution of clearness index to obtain a clearness value, K_t. The transformation can be expressed as follows (Graham et al., 1988)(see previous page).

The hourly solar radiation estimates are obtained using an empirical equation proposed by Graham and Hollands (1990) (see previous page).

Oxygen Consumption by Nitrification

Nitrification is a major factor in determining DO concentration. In previous models, nitrification was considered as a component of water column respiration. Water column respiration also includes the oxygen consumed in the oxidation of organic matter, phytoplankton dark respiration, and zooplankton respiration (Losordo, 1988; Culberson, 1993). For short term simulations, water column oxygen consumption rate has been considered to be a function of temperature only. However, for long term simulation, the rates of nitrification and oxidation of organic matter are different, and they cannot be considered as functions of water temperature only. In separating nitrification rate from other water column oxygen consumption processes, its rate is assumed to follow a first order model as a function of temperature and total ammonia nitrogen concentration. The inclusion of nitrification as a separate oxygen consumption term is also associated with the addition of ammonia nitrogen as a state variable to the pond model. In addition to nitrification, other processes affecting ammonia concentration, such as fertilization, fish feeding, and phytoplankton growth, need to be considered in the model. Oxygen consumption by nitrification is expressed as follows (Lee, et al. 1991):

$$MOnitr = 4.57\, K_N \theta^{(T-20)} N \qquad (7)$$

where,

K_N = nitrification rate, 1/hr;

q = water temperature dependence coefficient of nitrification;

T = temperature, ˚C; and

N = ammonia concentration, mg/l.

Results and Discussion

The model has been verified using PD/A CRSP data collected in Thailand. The model was run (for twenty simulations) using stochastically generated weather inputs to obtain maximum, minimum, and average values for output variables. The simulations were run for an 83 day period, from Julian day 40 to 123. Because observed hourly values are available for only six days during this period in 1988 (Julian day 40, 54, 68, 82, 96, and 110), the simulation hourly results are compared to the observed data for these six days. The simulated results are compared to the observed data including the cumulative probability curves of daily solar radiation, hourly solar radiation, temperature, DO, and fish weight (Figures 1 through 9).

The cumulative probability distributions of daily solar radiation values generated are compared to the measured data in Figure 1, showing good agreement. The hourly solar radiation values are compared to the observed data in Figure 2. The measured values fall within the range of generated values for most cases—only a few data points fall below the minimum simulate value obtained after twenty simulations, especially on Julian day 68. The cumulated probability functions were obtained using the data from 1990 to 1995. The generated data are compared with the data collected from Thailand in 1988. It was noted that the measured data in 1988 were much lower than the data measured from 1990 to 1995.

The simulated temperatures at three depths are shown in Figures 3 through 5. The observed data are not always within the range of simulated values. Although this is evident at the three depths, the differences are more pronounced for the surface water layer than for the middle and bottom layers. On Julian day 40, 54, and 82, the measured values are underestimated, while on Julian day 68 the values are overestimated. The maximum difference between the average simulated temperature and the observed value is 2.5˚C at the top layer on Julian day 40, the initial day of the simulation.

The comparison of hourly DO values at the three layers are shown in Figures 6 through 8. Most of the measured values available fall within the range of simulated values. The maximum DO difference between the observed and simulated values is 6.8 mg/l on Julian day 110 at bottom layer. The differences are caused, in part, by the lack of stratification evident in the measured

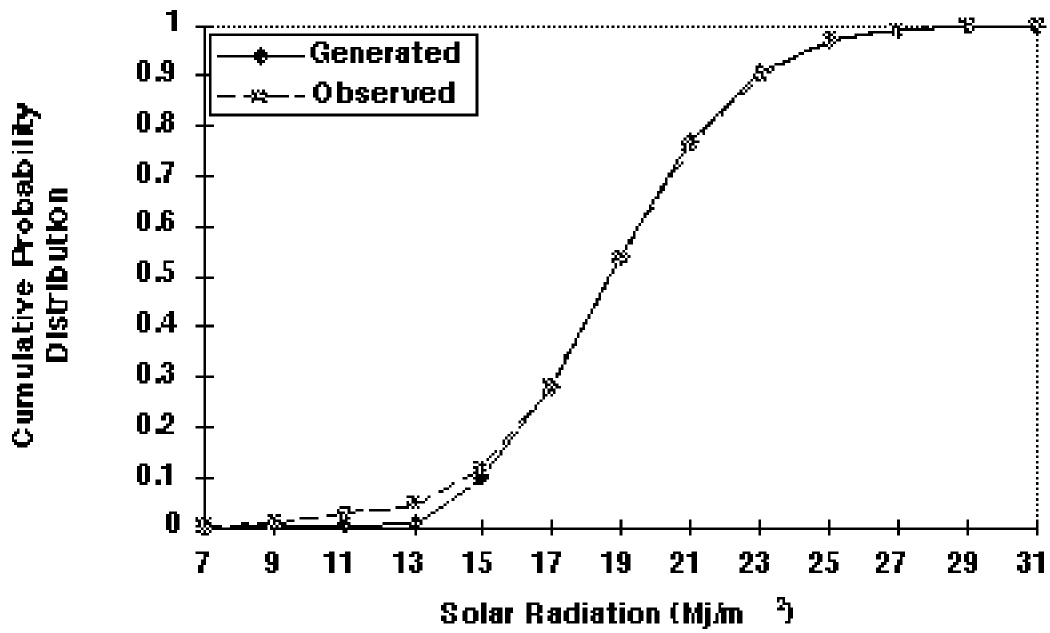

Figure 1. Comparison of the cumulative probability distribution curves between the generated and measured data.

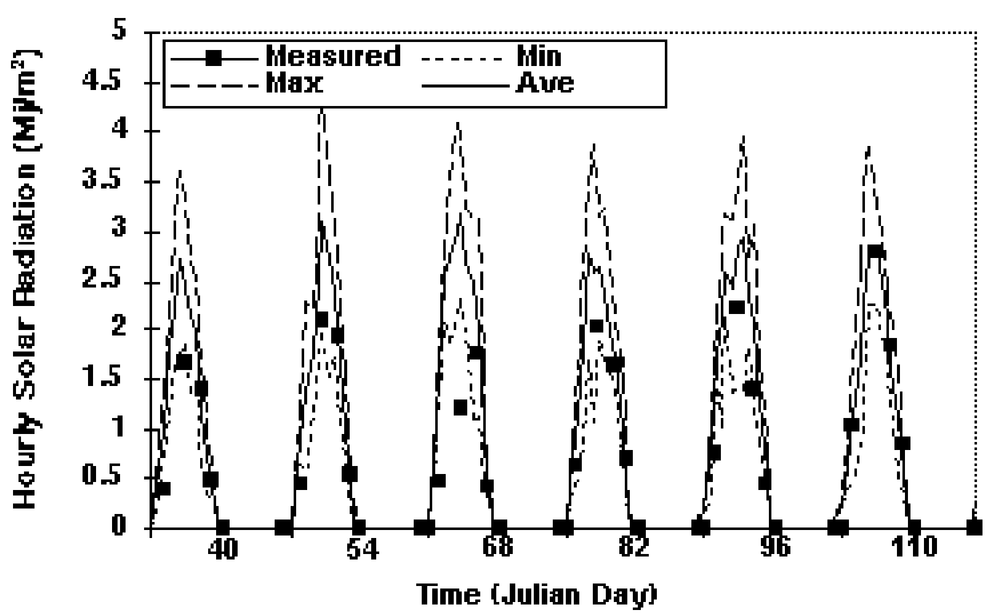

Figure 2. The generated hourly solar radiation values are compared to the measured hourly values on Julian day 40, 54, 68, 82, 96, and 110.

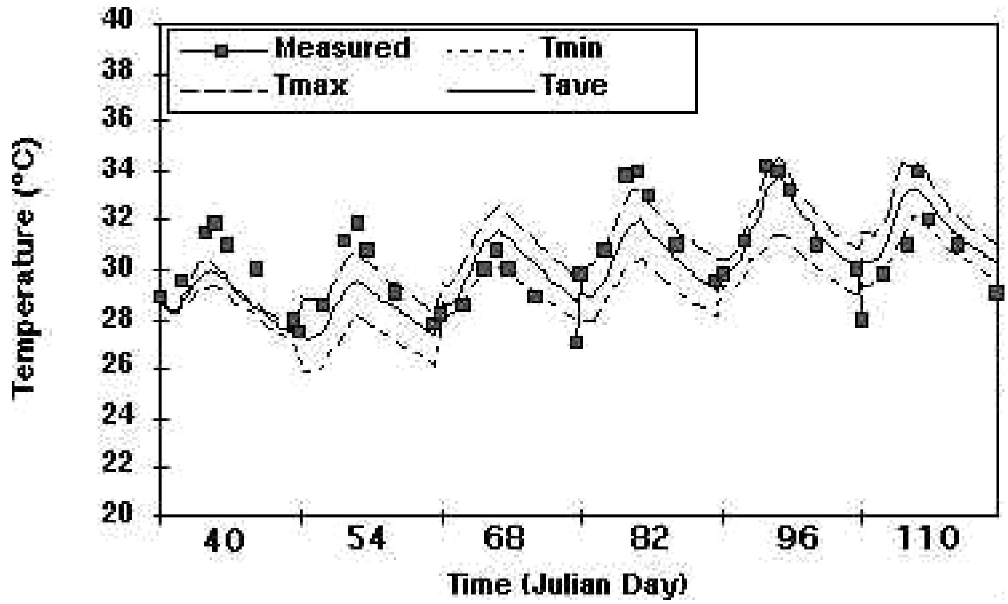

Figure 3. The generated maximum, minimum, and mean temperatures for the top pond layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

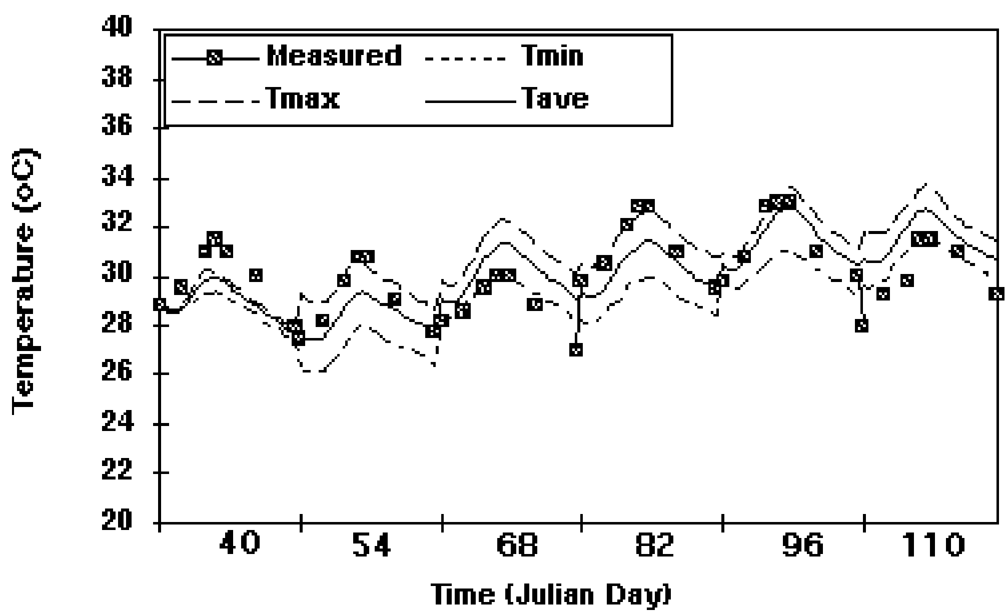

Figure 4. The generated maximum, minimum, and mean temperatures for the middle layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

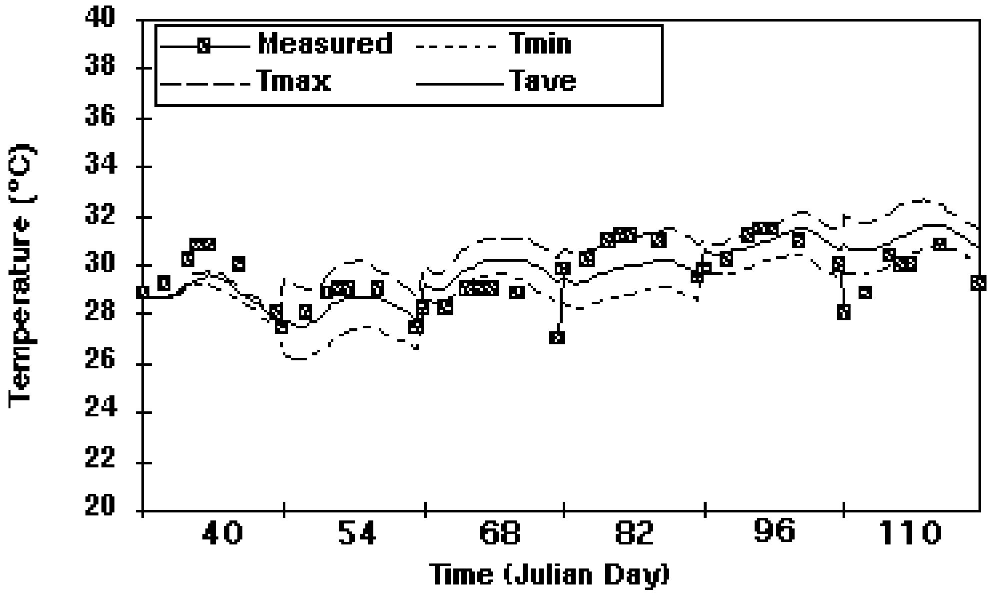

Figure 5. The generated maximum, minimum, and mean temperatures for the bottom layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

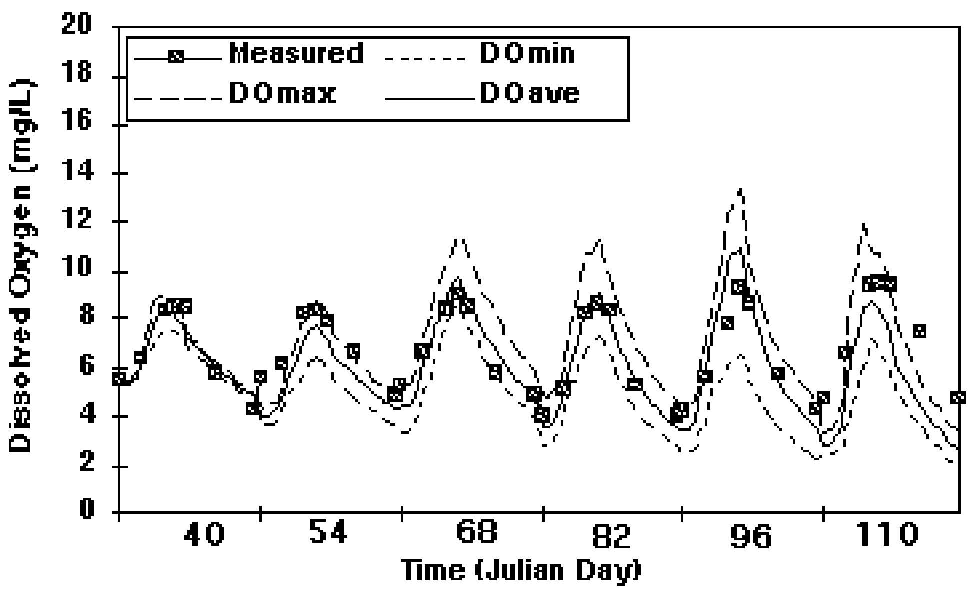

Figure 6. The generated maximum, minimum, and mean DO for the top layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

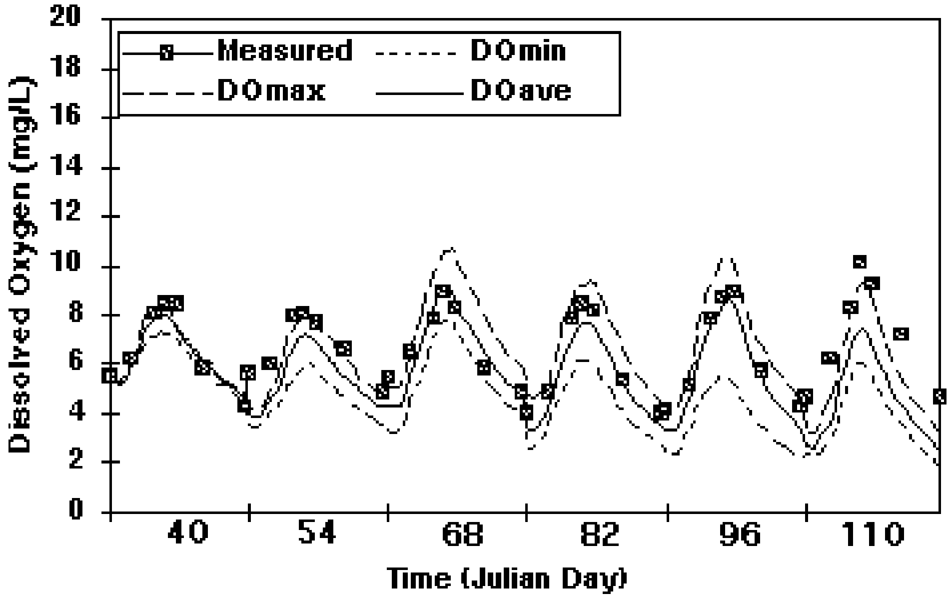

Figure 7. The generated maximum, minimum, and mean DO for the middle layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

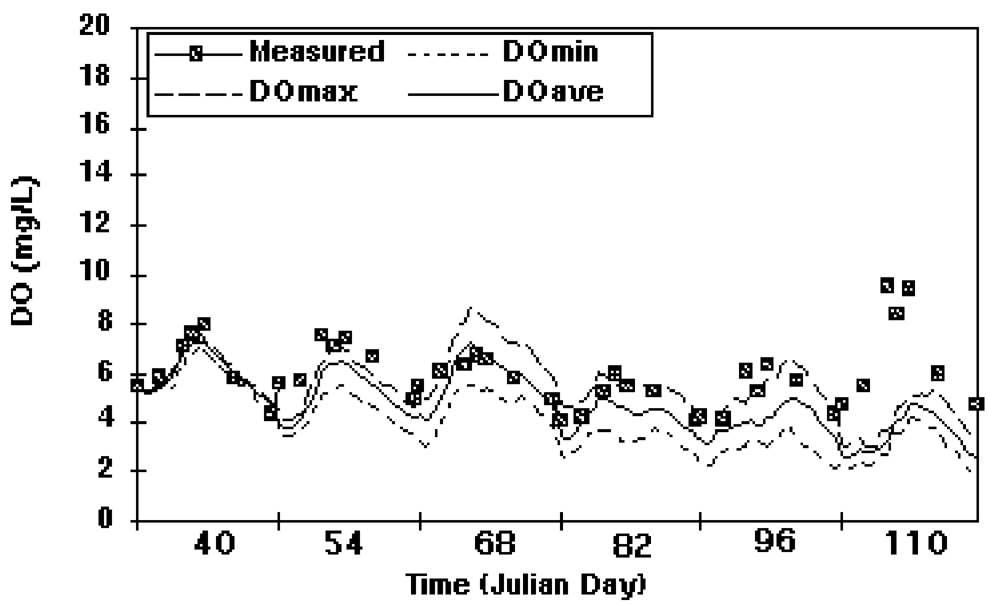

Figure 8. The generated maximum, minimum, and mean DO for the bottom layer are compared to the measured hourly data on Julian day 40, 54, 68, 82, 96, and 110.

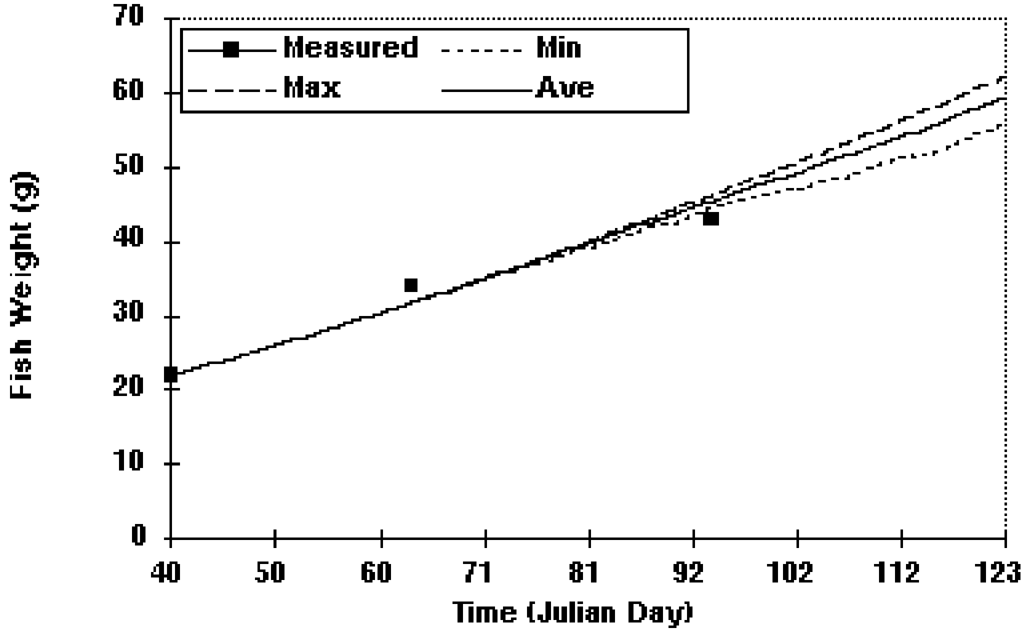

Figure 9. The generated maximum, minimum, and mean individual fish weight are compared to the measured data on Julian day 40, 64, and 97.

DO values while the simulations predicted stratified DO conditions. However, temperature stratification was predicted in the simulations (Figures 3 though 5). For this date, there appears to be a de-coupling of temperature and DO stratification which is not adequately considered in the model.

Although very limited fish growth data are available, measured values fall within the range of simulated values (Figure 9). The difference between maximum and minimum simulated values increases with time, indicating that the width of the probability distribution of the size of harvested fish increases with time.

Conclusions

The modified solar radiation sub-model provides an effective means of using limited data sets to estimate solar radiation values. The method is relatively simple and easy to couple with a water quality model. Temperature, DO, and fish growth simulation results follow measured values even for long term simulations of over 80 days. Although minor improvements to the model are still needed, very useful results can be obtained with the current version.

Literature Cited

Culberson, S.D., 1993. Simplified model for prediction of temperature and dissolved oxygen in aquaculture ponds: using reduced data inputs. M.S. thesis. University of California, Davis, USA, 212 pp.

Graham, V.A., K.G.T. Hollands, and T.E. Unny, 1988. A time series model for K_t with application to global synthetic weather generation. Solar Energy, 40(2):83-92.

Graham, V.A. and K.G.T. Hollands, 1990. A method to generate synthetic hourly solar radiation globally. Solar Energy, 44(6):333-341.

Jamu, D.M. and R. H. Piedrahita, 1996. Aquaculture pond modeling for the analysis of integrated aquaculture/agriculture systems. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report, Pond Dynamics/ Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 142-147.

Lee, J. H. W., Y. K. Cheung, and P.P.S. Wong, 1991. Dissolved oxygen variation in marine fish culture zone. J. Environmental Engineering, 117:799-815.

Liu B.Y.H. and R.C. Jordan, 1963. A rational procedure for predicting the long term average performance of flat plate solar collectors. Solar Energy, 7:53.

Losordo, T.M., 1988. The characterization and modeling of thermal and oxygen stratification in aquaculture ponds. Ph.D. dissertation. University of California, Davis, 416 pp.

Lu, Z. and R.H. Piedrahita, 1996. Stochastic modeling of temperature and dissolved oxygen in stratified fish ponds. In: H. Egna, B. Goetze, D. Burke, M. McNamara, and D. Clair (Editors), Thirteenth Annual Technical Report. Pond Dynamics/Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, USA, pp. 148-167.

Santos Neto, C.D. and R.H. Piedrahita 1995. Stochastic modeling of temperature in stratified aquaculture ponds.In: H. Egna, B. Goetze, and N. Weidner (Editors), Twelfth Annual Technical Report. Pond Dynamics/Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, Oregon, pp. 170-178.

III. Appendix A. Acronyms

AA	ammonium acetate
AIT	Asian Institute of Technology, Thailand
ALCON	Honduran feed company
ALCOM	Aquaculture for Local Community Development Programme (FAO)
ANDAH	Honduran National Association of Aquaculture
ANOVA	analysis of variance
AOAC	Association of Official Analytical Chemists
APHA	American Public Health Association
ARC/INFO	GIS application produced by Environmental Systems Research Institute
AS	absolute sensitivity
AWWA	American Water Works Association
BE	bioenergetics
BIFAD	Board for International Food and Agricultural Development
BMZ/GTZ	Bundesministerium für Wirtschaftliche Zusammenarbeit/ Deutsche Gesellschaft für Technische Zusammenarbeit
BOD	Board of Director
BOD	biological oxygen demand
BS	base saturation
BT	bull testes
BW	body weight
BWD	body weight per day
CEC	cation exchange capacity
CFB	crop or fish biomass
CIESIN	Consortium of International Earth Science Networks
CIFA	Committee for Inland Fisheries of Africa
CLSU	Central Luzon State University, Philippines
CM	chicken manure
CRSP	Collaborative Research Support Program
CTL	immersion in water alone
DA	dilute acid
DAP	diammonium phosphate
DAST	Data Analysis and Synthesis Team
DB	Database
DIN	dissolved inorganic nitrogen
dNPP	daytime net primary productivity
DO	dissolved oxygen
DOF	Department of Fisheries, Udon Thani, Thailand
DPF	days post-fertilization
ETH	immersion in ethanol vehicle
FAC	Freshwater Aquaculture Center, Central Luzon State University, Philippines
FAO	Food and Agriculture Organization
FCR	feed conversion ratio
FFR	fixed feeding rate
FISHBASE	database maintained by ICLARM/ FAO
GAMS	General Algebraic Modeling System
GIFT	genetic improvement of farmed tilapia
GIS	geographic information system
GMT	genetically produced male tilapia
GPP	gross primary productivity
HLLE	head and lateral line erosion
HPLC	high performance liquid chromatography
HQF	high quality feed
ICAP	plasma spectrophotometry
ICLARM	International Center for Living Aquatic Resources Management
IC	isolation column
ISNAR	International Service for National Agriculture Research
LBDA	Lake Basin Development Authority, Kenya
LQF	low quality feed
LR	lime requirement
Mb	mibolerone
MC	laboratory microcosm
MDHT	17α-methyldihydrotestosterone

ME	management entity
MOTAD	Target MOTAD methodology (risk programming model)
MSL	maximum sea level
MT	17α-methyltestosterone
NACA	Network of Aquaculture Centers in Asia Pacific
NAGA	ICLARM quarterly newsletter
NFI	natural food index
NFY	net fish yield
NGO	nongovernmental organization
NPP	net primary productivity
OM	organic matter
OM	percent oxygen matter
OSU	Oregon State University
PACON	Pacific Congress on Marine Science and Technology
PD/A CRSP	Pond Dynamics/Aquaculture Collaborative Research Support Program
PI	principal investigator
PL	post larval
POND©	decision support software developed by the PD/A CRSP
PONDCLASS	expert system software developed by the PD/A CRSP
PWV	pond water volume
RS	relative sensitivity
RWF	Rwandan francs ($1 US = 145 RWF)
SADC	Southern African Development Community
SD	stocking density
SE	standard error
SESA	Service des Enquêtes et des Statistiques Agricoles
SFCF	Sagana Fish Culture Farm, Kenya
SFR	satiation feeding rates
SMP	Developed buffer methods for determination of lime requirement of soils with appreciable amount of exchangeable aluminum.
SPN	Service de Pisciculture Nationale (National Fish Culture Service), Rwanda
SRP	soluble reactive phosphorus
SRO	relative phosphorus
SYSTAT	The System for Statistics
TA	total alkalinity
TAN	total available nitrogen
TC	Technical Committee
TH	total hardness
TKN	total Kjeldhal nitrogen
TP	total phosphorus
TSP	triple super phosphate
TSS	total suspended solids
TVS	total volatile solids
UCD	University of California, Davis
UNDP	United Nations Development Program
UNIX	operating system
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WE	water exchange
WID	Women In Development
WWW	World Wide Web

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NOTES