EIGHTH ANNUAL ADMINISTRATIVE REPORT

Pond Dynamics/Aquaculture

Collaborative Research Support Program 1990

Pond Dynamics/Aquaculture CRSP
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Collaborative Research Support Program

Eighth Annual Administrative Report

(1 September 1989 to 31 August 1990)

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This administrative report addresses the management and technical accomplishments of the Pond Dynamics/Aquaculture Collaborative Research Support Program during the reporting period of 1 September 1989 to 31 August 1990. Program activities are funded in part by the United States Agency for International Development, Grant: DAN-4023-G-SS-7066-00.

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I. Introduction

The Pond Dynamics/Aquaculture Collaborative Research Support Program (CRSP) is an international effort to develop aquacultural technology as a means of confronting food and nutritional problems. The program is supported in part by U.S. Agency for International Development (AID) grants awarded in 1982 and 1987, under authority of the International Development and Food Assistance Act of 1975 (P.L. 94-161). Oregon State University is the Management Entity for the CRSP and has technical, administrative, and fiscal responsibility for the performance of grant provisions.

The CRSP is a cohesive program of research that is carried out in selected developing countries and the U.S. by teams of U.S. and Host Country scientists. The U.S. institutions participating in the program are Auburn University, the University of California at Davis, and the Consortium for International Fisheries and Aquaculture Development (CIFAD). CIFAD members include the University of Arkansas at Pine Bluff, the University of Hawaii, the University of Michigan, Michigan State University, and Oregon State University.

CRSP activities were formally initiated on September 1, 1982 after several years of planning. From 1982 to 1987, CRSP projects involved the participation of government agencies and educational institutions in six host countries: Honduras, Indonesia, Panama, the Philippines, Rwanda, and Thailand. Due to funding constraints during 1986 and 1987, the CRSP was faced with reducing its operations. A plan for reorganization was submitted in December 1986 to the joint JCARD Panel on CRSPs and the USAID Agricultural Sector Council Subcommittee. The plan, which went into effect on September 1, 1987, called for maintaining a presence in each of the USAID geographical areas originally selected. Country sites were reduced to three: Rwanda, Thailand, and Panama. However, political initiatives in Panama in 1987 made it necessary for the CRSP to relocate to Honduras. Largely through the efforts of Auburn University, the CRSP was welcomed back into Honduras in April 1988 and began experiments with the assistance of the Honduran Department of Renewable Natural Resources (RENARE) in August 1988.

With the completion of the first three cycles of standardized global experiments (1982-1987), the CRSP began focusing on the statistical interpretation of data that were collected at the six project sites. The research program was successfully modified to reflect the reduction in sites without changing the overall emphasis of the CRSP. The global nature of the program therefore remained intact. Experimental protocol conforms to that of the previous three cycles. Field experiments blend program-oriented and project-oriented (site-specific) considerations in response to the results of the earlier experiments.

During this reporting period, the CRSP has actively pursued new funding opportunities to support project activities. The CRSP was successful in attracting funding in four target areas: economics research, gender studies, on-farm studies, and technology transfer. A new economics study was initiated in Thailand by researchers from the University of Arkansas at Pine Bluff and Michigan State University. This study complements the CRSP-funded economics study currently underway in Rwanda (see Section IV. of this report). Additionally, CRSP researchers at the University of Arkansas at Pine Bluff succeeded in getting funding for another study in Rwanda through a grant from USAID's Historic Black Colleges and Universities program. The proposal for a gender study of women in fishfarming, which was submitted to several donors by researchers from Oregon State University and Rwanda, has received funding. Activities for a workshop are planned for 1991. Other "buy-in" activities included: a proposal to USAID/Cairo for a comprehensive pond dynamics project in Egypt; a proposal to the International Center for Living Aquatic Resources Management (ICLARM) for collaboration on an aquaculture methods manual; and a proposal to the University of The Philippines for on-farm research.

Our CRSP has also benefitted from its involvement on the CRSP Council, a group composed of all eight USAID-funded Collaborative Research Support Programs. Through the Council, the PD/A CRSP participated in presentations to Congress, the World Bank, and environmental groups in the winter of 1990. One impact of this effort was to increase public awareness of our programs. The Council plans another series of presentations in 1991.

Many other technical and programmatic accomplishments are described in detail in this Eighth Annual Administrative Report, which covers the period from 1 September 1989 to 31 August 1990.

II. Summary of Activities and Accomplishments: September 1, 1989 to August 31, 1990

The major accomplishments of this reporting period include the development of cost-effective fertilization strategies, the creation of models on pond dynamics, the validation of models and expert systems, and continued efforts toward the dissemination of results and information.

Data Analysis and Synthesis

The University of Michigan component of the Data Analysis and Synthesis Team (DAST) continued to focus on the development of methods for analyzing fish growth, fish production, and pond limnology. Statistical analyses of the CRSP Central Data Base were used to identify ecological relationships important for understanding pond dynamics, and production models were developed to integrate the variables that are important to fish growth and yield.

Work on the validation and calibration of three mechanistic models described in previous reports continued at the University of California at Davis. Collaborative work with the University of Hawaii's Mariculture Research and Training Center and the Hawaii Institute of Marine Biology has provided additional data to be used in the model development process. The improved models will be useful in the analysis of new CRSP data sets and in the formulation of pond management guidelines.

At Oregon State University work on the CRSP expert system, called PONDCLASS, has progressed well. A preliminary version of the expert system is ready for use on Macintosh personal computers and is being developed for DOS-systems (IBM format). PONDCLASS is a user-friendly, computerized version of the pond management guidelines, and will serve as the basis for the printed version, the Manual of Pond Management Guidelines. When fully developed, PONDCLASS will advise users about the addition of nutrients to ponds in response to site-specific information that they provide regarding pond characteristics (chemical, physical, and biological) and local economic conditions.

Central Data Base

The Management Entity continues to maintain the CRSP Central Data Base for the storage and retrieval of standardized records from the research sites. At each site, data on physical variables (e.g., solar radiation, temperature, and rainfall) and chemical variables (e.g., water and soil chemical characteristics) are collected along with biological measurements (e.g., primary productivity, fish growth, and fish production). Whereas the resulting data sets are useful for *site-specific* studies, the compilation of all the individual data sets into the Central Data Base provides opportunities for many kinds of *global* analyses. Detailed standardized records such as those found in the Central Data Base are rare in the aquaculture literature.

The Central Data Base has continued to grow through the inclusion of new data, generated under the Fourth and Fifth Work Plans. New templates, created to reflect changes from previous work plans, were distributed to the CRSP participants.

The utility of the Central Data Base extends beyond the needs of the PD/A CRSP. The Central Data Base was designed to facilitate communication with other large databases, such as the Tropsoils CRSP data base, thereby creating opportunities for collaboration. ICLARM (the International Center for Living Aquatic Resources Management) plans to incorporate some of the CRSP Central Data Base into a more general fisheries and aquaculture data base called FISHBASE. FISHBASE, an interactive data base on tropical fisheries management, is being compiled by researchers from ICLARM, Germany (GTZ), and the Food and Agriculture Organization (FAO) of the United Nations.

The CRSP Central Data Base also serves as a storage and retrieval center for standardized data from *any* research site. CRSP scientists as well as scientists in the aquaculture community at large may contribute to and access the data base. Data are available on computer diskettes or in print as in PD/A Collaborative Research Data Reports. During this reporting period information and data have been sent to aquaculture researchers overseas and in the United States in response to requests for access to the CRSP Data Base.

Field Sites

Honduras. Honduras has experienced a phenomenal 600% growth in the demand for tilapia fingerlings since 1986. At the El Carao station (Comayagua), CRSP researchers from the Honduran Department of Renewable Natural Resources and Auburn University are developing new technologies to increase tilapia fry production. In the past year, they studied the effects of hormone treatment, fry stocking rate, temperature, soil characteristics, benthic respiration, fertilization, and feed on fish production.

Environmental conditions in Honduras permit the year-round operation of fish farms although seasonal differences may affect the efficacy of hormone treatment. Researchers conducted a stocking density experiment using hormone-treated male tilapia, and found that production of sex-reversed fry could be increased by 34 to 70% over existing levels by increasing stocking rates and modifying the duration of treatment. They also established guidelines for hormonal treatment of tilapia fry using such indicators as fry size and water temperature.

Researchers found evidence that primary productivity and fish yield in organically fertilized ponds at El Carao have been limited by a combination of low nitrogen and low light penetration due to mud turbidity. They used results from CRSP research in Thailand, where organic fertilizers were enhanced with nitrogen, to determine effective fertilizer regimes in Honduras. Because the cost of nitrogen supplements (inorganic fertilizers) is expensive, they recommended that low to moderate levels of inorganic fertilizer be used in conjunction with less-expensive organic fertilizers. In a related study with feeds and fertilizers, researchers determined that farm profits can be increased by using a combination of chicken litter and feed at a stocking density of two fish per square meter. However, using chicken litter alone (without feed) at lower stocking densities proved more cost-effective. Researchers then added another level of complexity by studying the effects of feed and fertilizer combinations on the polyculture of tilapia and *Colossoma*. *Colossoma* is gaining popularity as a food fish in Honduras but techniques for its cultivation are poorly understood. Although much remains to be learned, researchers were able to recommend from this study that fish farmers should not stock *Colossoma* in ponds with tilapia if they are unwilling or unable to invest in a supplemental (and often expensive) commercial diet.

Rwanda. CRSP researchers in Rwanda (National University of Rwanda, Oregon State University, and Auburn University) continued to study the use of locally available organic materials as inputs for increasing fish production. In-pond composts of various mixtures of grasses, leaves, and manures are commonly used to fertilize fishponds throughout rural Africa. Researchers hypothesized that the slow decomposition of organic fertilizers (e.g., composted grasses) suggests that high initial rates of fertilizer application may be beneficial to fish production. They tested this hypothesis in mixed-sex tilapia culture, where they surmised that the benefits of high initial fertilization would be greatest. However, they found that the high initial application rate resulted in lower yield than the constant application rate, and that this decrease was particularly evident at the higher stocking density tested (two fish per square meter). They also found that the growth of male fish was hindered more than that of female fish as stocking densities increased.

In a companion study, researchers evaluated new management strategies for the efficient application of composts. They recommended that weekly applications of low-quality organic matter such as fresh grass should not exceed 5-7 kg per are (100 m^2). Higher rates may lead to reductions in fish growth and survival. Where the availability of grass is limited, researchers suggested that fresh vegetable matter be supplemented with inorganic nitrogen or phosphorus to increase fish yield.

Researchers from the University of Arkansas at Pine Bluff joined the other CRSP researchers in Rwanda in a study of the effects of elevation on fish production. Most of the 3000 fishponds in Rwanda are situated in mid-elevation zones (1500-1700 m); few ponds are found in the upper elevation zones partly because the extension service has not encouraged tilapia farming at high elevations. During this past year, researchers began investigating how improved pond management practices might remove some of the constraints to high-elevation tilapia culture. Socioeconomic aspects were included in the overall scheme of pond dynamics studies in order to examine resource-use efficiency. Researchers found that farmer interest was remarkably high at the upper elevations, and that fishponds provide greater revenues per unit area than traditional agriculture.

Thailand. As fish yield increases with increasing fertilization, balancing manure and inorganic supplements becomes essential. Researchers from three US universities (The University of Michigan, Michigan State University, and the University of Hawaii) and two Thai institutions (the Asian Institute of Technology and the Royal Thai Department of Fisheries) developed new technologies for maximizing nutrient efficiency while minimizing the occurrence of adverse environmental conditions for the fish. They were able to double yields reported in the literature by nominally loading ponds with chicken manure (at 75 kg/ha/wk) that is supplemented with nitrogen and phosphorus. Like the studies in Rwanda and Honduras, this study examined some of the economic factors (such as cost of inorganic fertilizers) that would ultimately determine the effectiveness of these management recommendations.

Other studies in Thailand focused on ecosystem dynamics, bioenergetics, pond stratification, and biometry. CRSP researchers recommended better methods for reporting fishpond yield by revising statistical techniques that are currently practiced by aquaculturists. Researchers also evaluated the relative merits of mixing devices that are used to destratify ponds. Destratification strategies have become important for the cost-effective intensification of pond aquaculture.

Host Country Special Topics Research included an examination of the role of sediments in pond fertility in Thailand, and the evaluation of sampling techniques commonly used to estimate fish size. Another Special Topics Research study focused on the comparative growth and mortality of tilapia and *Clarias gariepinus* (catfish) in Rwanda. *Clarias* is widely used throughout Africa to control overproduction of tilapia fingerlings in ponds, a condition that usually leads to lower individual fish weights at harvest. All studies contributed to a better understanding of pond dynamics and to the development of improved production techniques for ponds.

Information Dissemination, Technology Transfer, and Other Activities

Ancillary to the Global Experiment, but still important to the overall goals of the CRSP, are activities geared toward country-specific research and extension needs. All U.S. staff overseas contribute some time to extension work such as training students and technicians, teaching short courses on aquaculture, conducting site-specific experiments, and working with local extension agents and farmers. The number of individuals involved in all forms of training, from non-degree activities to work on advanced degrees, has grown to well over 400 since the beginning of the CRSP. These activities are described in the sections "Public Service and Project Development," and "Program Management and Technical Guidance."

During this reporting period, CRSP researchers and staff from the Program Management Office greatly broadened the contact of this CRSP with the world aquaculture community through dissemination and publication of research results. The rate at which results are being published in the scientific literature continues to climb. CRSP publications, now numbering over 330, are distributed to a broad domestic and international audience. Detail on our results and publications is presented throughout this report.

III. CRSP Research Program: Background, Design, and Implementation

The Pond Dynamics/Aquaculture CRSP has three components:

- the Global Experiment;
- a U.S. research component composed of projects conducted by the Data Analysis and Synthesis Team as part of the Global Experiment and Special Topics Projects at participating U.S. universities; and
- Special Topics Projects in Host Countries.

Under the initial phase of the Program (1981-1987) the Global Experiment and related data synthesis activities were the major focus of this CRSP and accounted for more than 90% of the total research program. Special Topics Projects in the U.S. and in Host Countries complemented the Global Experiment. Under the Continuation Plan (since 1987) increasing emphasis has been placed on site-specific research and the testing of hypotheses developed during the first three experimental cycles. These research activities, their purposes, and their present status are described in this section.

The CRSP Global Experiment

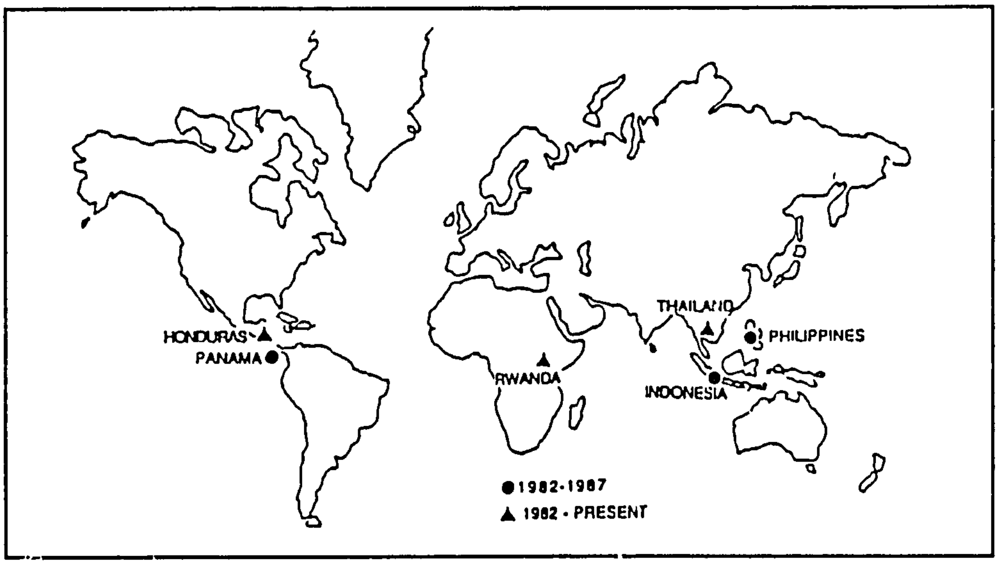
The long-range goal of the CRSP is to increase the availability of animal protein in less developed countries through pond aquaculture. The strategy adopted by the CRSP in pursuit of this goal is to undertake the basic research required to improve the efficiency of pond culture systems. A technical plan consistent with this strategy was developed under a planning study funded by USAID (Specific Support Grant AID/DSAN-G-0264). The technical plan reviewed and synthesized literature on state-of-the-art pond aquaculture and undertook overseas site visits to determine research needs and availability of local support in less developed countries. The findings from these surveys were then translated into planning guidelines.

In the course of the planning activities it become apparent that there are two important aspects of improving the efficiency of pond culture systems. First, there is a need to improve the technological reliability of pond production systems. Second, there is a need for economic optimization consistent with local conditions.

The need for improved production technologies is manifest in the wide variation observed in the productivity of different pond systems. Pond aquaculture has been practiced for centuries as a highly developed art form and the literature is replete with reports about practices that have produced high yields. However, when the same practices are applied to other ponds, the results often are not reproducible. It is clear that there are subtle differences regulating productivity from pond to pond and from site to site, but the nature of these differences remains obscure.

The need for rigorous economic analyses of pond aquaculture systems is typically encountered in attempting to formulate appropriate aquaculture development strategies, both in developing countries and in the U.S. In order to determine if contemporary pond management practices are the most efficient approach to fish production, it is necessary to develop quantitative production functions to facilitate analyses of the various strategies or combinations thereof. It is not presently possible to develop these functions without making numerous and often tenuous assumptions, because the dynamic mechanisms regulating the productivity of the ponds are poorly understood and the existing data base is inadequate. The common denominator in improving production technologies on the one hand and facilitating economic analyses on the other, therefore, is clearly an improved understanding of pond dynamics.

The Pond Dynamics/Aquaculture CRSP is unique relative to other CRSPs in several ways. The most visible difference is that it is funded at a substantially lower level. A less obvious difference is that whereas other CRSPs are composed of a cluster of related projects organized on disciplinary or geographical bases, this CRSP is organized around a single global experiment that involves all of its participants. Additionally, this CRSP is one of the few that was planned by the participating institutions.



Experimental Design

During the planning of this CRSP, it became apparent that the inadequacy of the existing pond aquaculture data base was a major constraint to improving the efficiency of pond culture systems. The abundant technical literature about pond aquaculture can provide general guidelines for the operation of pond culture systems. However, because of the lack of standardization in experimental design, data collection, and analysis, these reports cannot be statistically compared to one another and are consequently of limited utility for predicting the performance of pond culture systems. The approach taken by the CRSP to develop quantitative expressions to improve production technologies and facilitate economic analyses has been to conduct standardized experiments and to develop a standardized data base that can be used to quantitatively evaluate pond performance over a broad range of environments.

The initial statistical design for the experiment involved monitoring environmental and fish production variables at seven geographical locations. The location of project sites was carefully selected to include a geographical cross-section of the world where advances in pond aquaculture would be most beneficial and apt to succeed. Since September 1, 1987, the program has conducted experiments in only three of the countries originally selected, but continues to represent the three major regions of the tropics— Southeast Asia, Africa, and Latin America. All of the sites lie within a zone 15 degrees north or south of the equator. Observations specified in annual work plans are made on 12 or more ponds of similar size at each location. The variables observed, frequency of observation, and materials and methods are uniform for all locations.

Observations at each location are analyzed by the research team involved at that location. Data from all sites are also filed in the CRSP Central Data Base, where they are accessible for analysis by the Data Analysis and Synthesis Team. Standard statistical methods are used to test hypotheses about correlations between variables and to evaluate the sources of variation within ponds, between ponds within locations, and between locations. Because of the relatively large number of locations and ponds at each location, the experimental design has substantial statistical power.

CRSP Work Plans

The CRSP technical plans (Work Plans) are developed by the CRSP Technical Committee. For the first three cycles, each CRSP Work Plan represented a detailed experimental protocol for one experimental cycle. A cycle involved two series of observations of four- to five-months duration. One set of observations was made during the dry season and the other during the wet season.

Five work plans have been developed to date. The rationale of the First Work Plan was to manage all ponds in exactly the same way to establish a detailed baseline of data on pond variables. The plan specified standardized methods for pond preparation and monitoring. It was developed at a meeting of CRSP participants in Davis, California on March 2-3, 1983.

The Work Plan for the second experimental cycle was developed at a meeting of CRSP participants in Atlanta, Georgia on April 10-12, 1984. At this meeting, participants reviewed accomplishments and discussed problems encountered during the first cycle of experiments. They then developed a detailed plan for the second experimental cycle. In this experiment, the responses of ponds receiving organic fertilizers were compared to those of ponds receiving inorganic fertilizers.

The third cycle of pond dynamics experiments was developed by CRSP participants at their meeting in Honolulu, Hawaii on March 18-20, 1985. Based upon their experiences to date, the Third Work Plan was developed to compare the responses of ponds to varying levels of organic fertilizer.

The Fourth Work Plan was developed by the CRSP Technical Committee at their meeting in Portland, Oregon on February 25-26, 1987. CRSP participants reviewed the progress of the first three cycles of the Global Experiment. Specific statistical hypotheses were formulated for research in Host Countries and the United States based upon results of previous experiments. New experiments were designed to allow the collection of standardized data for the CRSP Central Data Base. This work plan was further refined at the Technical Committee Meeting in Kona, Hawaii on January 11-14, 1988. As recommended by the External Evaluation Panel during the first Triennial Review, the Fourth Work Plan encompassed two years of experimental protocols rather than one. A biennial work plan was adopted because it avails greater opportunity for results to be analyzed before planning subsequent research.

The Fifth Work Plan was developed during the CRSP Annual Meeting in Davis, California on May 1 to 4, 1989. This work plan follows the same approach as the Fourth Work Plan in that different, but related, experiments will be conducted at the various sites. The particular topics to be studied at each site were selected on the basis of the aquaculture research needs of each country. In addition to the research carried out at those sites and by participants in the U.S., experiments with farmer-cooperators in the host countries are planned. Like the Fourth Work Plan, the Fifth encompasses two years of experimental protocols; activities specified in it were undertaken during this reporting period, and will continue through August 31, 1991.

During this reporting period the Technical Committee has begun work on the Sixth Work Plan, which will describe research activities to be undertaken during the period from September 1, 1991 through August 31, 1993.

Data Management

Consistent with its long-term goal, the CRSP is working toward the development of practical pond management models to improve the efficiency of pond culture systems. The development of quantitative models is dependent upon the efficient management of s' dardized data.

Standardized data are tabulated at each research location in accordance with CRSP work plans. Project teams may conduct independent analyses of their data and publish results if they so desire. However, in all cases, the data are transmitted to a centralized CRSP Data Base maintained by the Management Entity. In this way, the entire data set is available to all CRSP participants, but especially to the CRSP Data Analysis and Synthesis Team. The latter body was appointed by the CRSP Board of Directors to accomplish data analysis, synthesis, and model development. The various activities of Team members are supported as part of the U.S. Research Component.

The CRSP Central Data Base was brought completely up-to-date prior to the beginning of activities under the Fifth Work Plan. This consisted of the translation and verification of *all* data that were manually input into personal computers at the seven field sites during the first three experimental cycles. Each site made approximately 90,000 observations per year of 96 variables. This amounted to over one-half million observations that were compiled and translated into standardized formats. During this reporting period data from the fourth and fifth experimental cycles were added to the data base.

The current status of the data base facilitates communication with other large agricultural data bases. More importantly, it allows researchers worldwide ready access to data from the Global Experiment.

Third Year In A New Phase of The Global Experiment

During this reporting period, the CRSP continued the new phase of operations begun under the Continuation Plan. Under this plan, which covers CRSP operations from September 1, 1987 through August 31, 1990, research continues at three sites, in Rwanda, Honduras, and Thailand. These sites are representative of the three USAID geographical areas in which the CRSP conducts overseas research: Africa, Latin America, and Southeast Asia. In 1987 the CRSP was able to implement a reduction in the number of research sites without altering the overall emphasis of the program.

The continuation plan centers on a conceptual model of pond culture systems that was developed by CRSP scientists (Figure 1). The model was used to identify more specific research needs for incorporation into future work plans. New experiments build on the results of previous CRSP research in a continuing effort to enhance the understanding of the dynamic processes that regulate the productivity of aquaculture ponds.

The Fifth Work Plan, a continuation of the new phase of research under the reorganization of the CRSP, was implemented during this reporting period. The CRSP Technical Committee refined this work plan during the year and expanded it to a biennial work plan. The Sixth Work Plan is currently being developed by the Technical Committee. It will emphasize the calibration and verification of predictive models under field conditions, and field testing of provisional pond management practices.

IV. Research Program Accomplishments

The Global Experiment

The global nature of the Pond Dynamics/Aquaculture CRSP is evident in the interrelationships among projects. The program consists of tightly knit research projects that share the long-term goal of increasing the availability of animal protein in less developed countries through pond aquaculture.

Project emphasis is placed on standardized experimental design and data collection. Standardization permits the comparison of data from diverse geographical locations. The experimental design involves monitoring environmental and fish production variables in twelve or more ponds at each of three geographical locations in accordance with standardized work plans.

The five cycles of the Global Experiment that were completed followed one another logically. Although the main objective changed from cycle to cycle, consistency in experimental design allows the comparison of results between cycles. The global nature of the program will be preserved in the experimental cycles to come. The experimental protocol for the next cycles will remain consistent with that used in the Global Experiment. Furthermore, with the completion of the CRSP Central Data Base, the world aquaculture community may contribute to and begin to use the wealth of data amassed by the CRSP.

Results of the Global Experiment

The sixth year of the CRSP's Global Experiment, under the Fifth Work Plan, was successfully completed at each of the three research locations: Rwanda, Honduras, and Thailand. Experiments at the freshwater sites in Rwanda, Thailand, and Honduras dealt with a wide range of important problems, including the effects of different stocking densities on production, the use of other species in polyculture with tilapia, changes in the soils of fish ponds over time, the optimization of feeding in conjunction with the fertilization of ponds, supplementation of organic fertilization with inorganic fertilization, and studies on the hormonal sex reversal of tilapia. *Oreochromis niloticus (Tilapia nilotica)* was stocked at all sites. Species used in polyculture studies included *Clarias gariepinus* in Rwanda, and *Colossoma macropomum* ("tambaqui") and *Cichlasoma managuense* ("guapote tigre") in Honduras.

The Fourth and Fifth Work Plans differ from earlier work plans in that hypotheses about pond dynamics are tested in different field experiments at each research location. This procedure allows the CRSP to proceed rapidly through the testing process. The Global Experiment was further enhanced by addition of intensive sampling periods and diel studies. *Standard Methods* (Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 1985) continued to be used for recommending materials and procedures for collecting data. Additional detail on the Fifth Work Plan is presented in Appendix C.

The experimental protocols for the sixth year of the Global Experiment are provided in the Fifth Work Plan. Technical progress for this past year is described briefly for each site.

Honduras Technical Reports

Supplemental Nitrogen Fertilization of Organically Fertilized Ponds

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Introduction

There is evidence that primary productivity and fish yield in organically fertilized ponds at El Carao have been limited by a combination of low nitrogen and light limitation due to mud turbidity. An initial step to discovering the relative contribution of each factor to productivity limitation would be to supplement organic fertilizers with nitrogen. The Thailand CRSP demonstrated that fish yield could be increased by supplementing organic inputs with high rates of nitrogen. Due to the high cost of inorganic nitrogen, it is probable that only low to moderate rates of nitrogen fertilization would be profitable in Honduras.

The objectives of this experiment were to determine the influence of nitrogen on primary productivity in ponds at El Carao by supplementing organic fertilization with the addition of inorganic nitrogen at a moderate level. If moderate levels of nitrogen result in increased primary productivity, then further research will be conducted to optimize supplemental nitrogen fertilization.

Materials and Methods

Six 1000-m^2 ponds at El Carao were stocked with sex-reversed *Oreochromis niloticus* males at 1 fish/m^2, and *Cichlasoma managuense* (guapote tigre) at 0.025 fish/m^2 to control tilapia reproduction. All ponds were fertilized weekly with chicken litter at 750 kg total solids/ha, and three of the ponds were also fertilized weekly with urea at 10 kg N/ha. Fish were sampled at monthly intervals and were harvested on 19 June 1990, 126 days after stocking.

Chlorophyll *a*, total ammonia nitrogen, pH, and Secchi disk visibility were measured two times a week, and filterable orthophosphate, total phosphorus, organic nitrogen, total solids, and volatile solids were measured once a week. Zooplankton were filtered from 14 liters of water using an 80-μ mesh net, and enumerated weekly according to the major groups: copepoda, cladocera, rotifera, and nauplii. Daily wind speed, solar radiation, evaporation, and rainfall were recorded. Production data were subjected to a partial economic analysis, where net income was the total income from fish sales minus the cost of chicken litter and urea. The prices of fish, chicken litter, and urea were 4.40, 0.09, and 1.28 Lempiras/kg, respectively. Soil samples were taken from 9 discrete locations in each pond during a related soils study. Data were analyzed by unpaired t-tests and regression analyses. Differences were declared significant at an alpha level of 0.05. The null hypothesis was that supplemental nitrogen fertilization would have no impact on the variables being measured.

Results

Mean chlorophyll *a* and total ammonia nitrogen were significantly greater in ponds treated with urea, whereas total phosphorus and filterable orthophosphate were significantly less (Table 1). Fish yield, organic nitrogen, and volatile solids were not significantly greater in nitrogen-fertilized ponds, despite a relatively large increase in chlorophyll *a* (Table 2).

Table 1. Pond and treatment means of water quality variables measured during a 126-day growth trial of *Oreochromis niloticus* in ponds treated with chicken litter or chicken litter and urea.

Treatment	Pond	Chlorophyll a (ug/l)	Secchi disk (cm)	Organic nitrogen-N (mg/l)	Total ammonia-N (mg/l)	Total P (mg/l)	Filterable PO_4-P (mg/l)	Total Alkalinity (mg $CaCO_3$/l)	Volatile Solids (mg/l)	Ash (mg/l)
Manure Only	B1	278.2	14.6	3.27	0.07	3.94	2.52	140.3	0.156	0.234
Manure Only	B9	380.0	13.2	3.64	0.10	4.88	2.89	180.6	0.157	0.304
Manure Only	B10	373.5	13.1	3.61	0.10	4.38	2.57	187.9	0.197	0.273
	Mean	344 *	13.6	3.51	0.09 *	4.40 *	2.66 *	169.6	0.17	0.27
	Stand Error	32.9	0.5	0.121	0.011	0.274	0.118	14.8	0.014	0.020
Manure+Urea	B3	481.3	12.0	3.84	0.14	3.77	2.15	167.2	0.213	0.236
Manure+Urea	B5	486.6	12.4	3.73	0.15	3.10	1.60	142.8	0.187	0.231
Manure+Urea	B12	445.3	12.6	3.79	0.19	3.57	2.04	144.8	0.170	0.226
	Mean	471 *	12.3	3.79	0.16 *	3.48 *	1.93 *	151.6	0.19	0.23
	Stand Error	13.0	0.2	0.034	0.016	0.198	0.168	7.8	0.013	0.003

* Differences between treatment means are significant ($P \leq 0.05$).

Table 2. Pond and treatment means for fish production during a 126-d growth trial of *Oreochromis niloticus* stocked at $1/m^2$ at an initial weight of 13.1 g, and treated with chicken litter or chicken litter plus urea.

Treatment	Pond	Harvest Mean wt. (g)	Harvest Gross yield (kg/ha)	Harvest Survival (%)	Net Income (Lps./ha)
Manure Only	B1	162.4	1427.2	86.2	5132
Manure Only	B9	164.5	1357.1	82.5	4824
Manure Only	B10	170.4	1419.6	83.3	5099
	Mean	166	1401	84	5018
	Stand Error	2.4	22.2	1.1	97.7
Manure+Urea	B3	166.6	1379.3	82.6	4421
Manure+Urea	B5	180.2	1413.1	78.4	4570
Manure+Urea	B12	182.7	1789.6	97.9	6227
	Mean	177	1527	86	5073
	Stand Error	5	131.5	5.9	578.6

These results indicate that increases in plankton biomass were not proportional to increases in chlorophyll *a*. There was no correlation between total ammonia and chlorophyll *a* when all data were included. However, when only concentrations of total ammonia less than or equal to 0.1 were included, there was a significant relationship (Figure 1) indicating that fertilization with urea to produce concentrations of residual nitrogen higher than 0.1 mg/L may not be necessary. Smaller additions of urea may result in equal increases of chlorophyll *a*. The effects of treatments on soil chemistry could not be tested, because chemical analyses of soil samples have not yet been completed.

The value of supplemental nitrogen fertilization will ultimately be determined by its profitability. In this study, net income was not significantly different between treatments. During the season, 500 Lempiras/ha of urea was invested to produce 554 Lempiras/ha more fish in urea-fertilized ponds. The use of supplemental nitrogen might be more profitable if it were applied in smaller quantities, or applied only during the last half of the season, when higher natural productivity is necessary to sustain a higher biomass of fish. Additional research will be necessary to establish optimal levels of supplemental nitrogen fertilization.

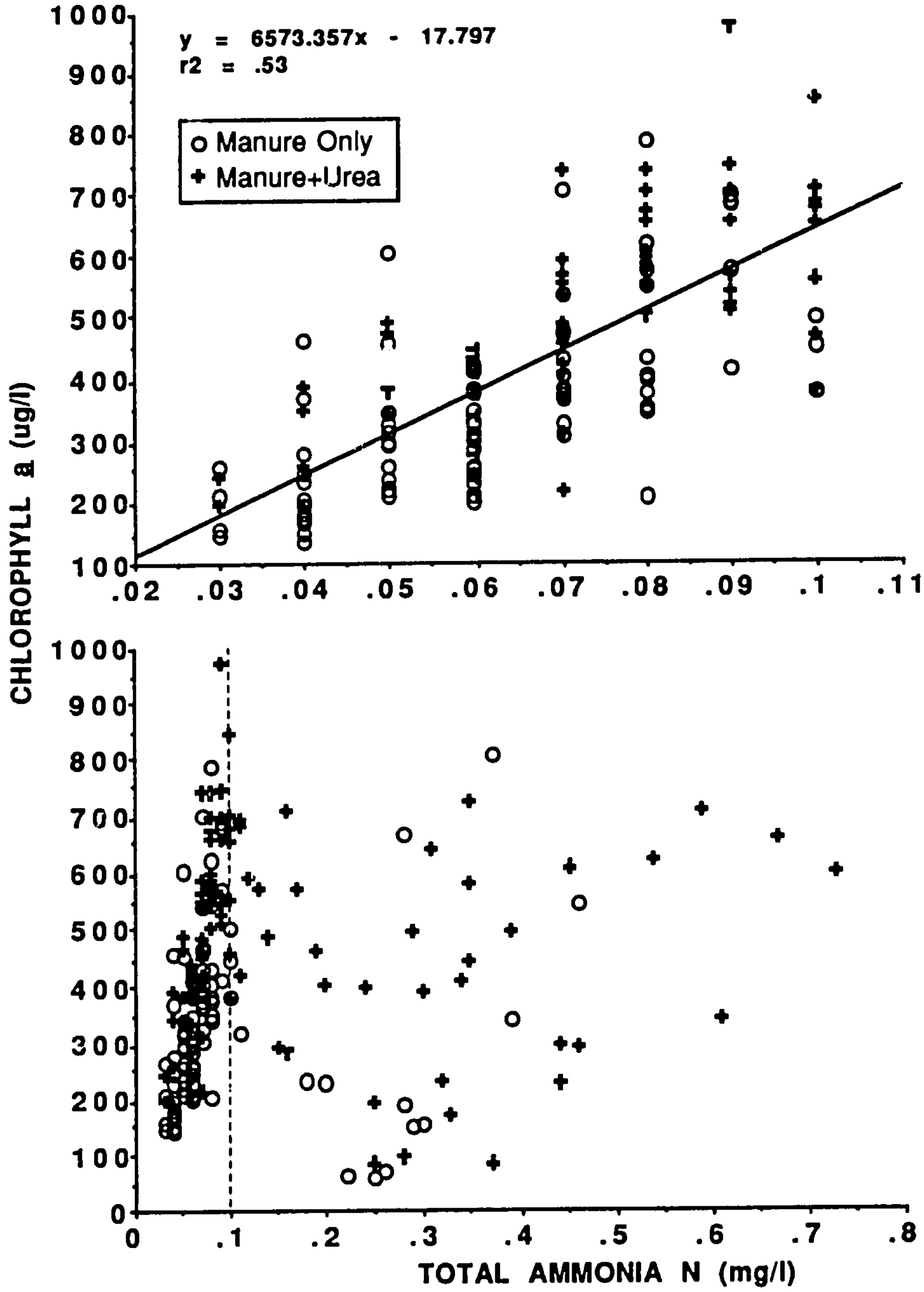

Figure 1. Relationship of chlorophyll *a* with total ammonia. The bottom graph includes all data, and the dashed line indicates the dividing point for data included in the top graph.

Effects of Fry Stocking Rate, Hormone Treatment Duration, and Temperature on the Production of Sex-Reversed *Oreochromis niloticus*

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Introduction

Sex reversal of *Oreochromis niloticus* at the National Aquacultural Research Center, Comayagua, Honduras began in February 1988, and since then more than 2.2 million fry have been treated successfully. Fry stocked into hapas made of 1.6-mm Ace nylon mesh and placed in fertilized earthen ponds were fed a hormone-treated diet (23% protein; 60 mg methyltestosterone/kg feed) four times daily. The average stocking rate of fry in hapas was 4,300 fry per m^2 of water surface area (range: 2,000-5,200 fry/m^2). Hormone treatment generally lasted 28 days and resulted in 98% phenotypic males.

Manipulation of the fry stocking rate or the duration of the hormone treatment may result in significant increases in the production of sex-reversed fry. In Honduras, environmental conditions permit year-round operation although seasonal temperature differences may affect the efficacy of hormone treatment. The purpose of this experiment was to determine the effects of fry stocking rate and hormone treatment duration on the sex-reversal of *Oreochromis niloticus* fry in hapas suspended in ponds.

Materials and Methods

A completely randomized, 3 x 2 factorial experimental design was used. The treatments tested were three fry stocking rates (2000, 4000, or 6000 fry/m^2) and two hormone treatment periods (21 and 28 days). Each treatment was replicated twice. Uniform-age fry harvested from a reproduction pond were graded through 3.2-mm mesh Vexar to obtain 9- to 11-mm fry for hormone treatment. Fry were stocked into hapas (1m x 1m x 1m; 1.6-mm Ace nylon mesh) at the prescribed rates. The number of fry stocked was estimated by visual comparison to a counted sample of 1000 fry. A random sample of 500 fry was obtained from the entire population before stocking. All fry in the sample were measured to the nearest mm, and the whole sample was weighed to the nearest 0.01 g.

Methyltestosterone was incorporated into ground, sifted (560-µ mesh sieve) commercially available feed (23% protein) at a concentration of 60 mg/kg feed. Feeding rates were 20% of biomass/d during the first week, 15% of biomass/d during the second week, 12% of biomass/d during the third week, and 10% of biomass/d during the fourth week. The daily ration was divided into four equal portions and offered at 0800, 1000, 1200, and 1400 hours. Fry in replicate hapas were fed the same quantity of feed daily. Upon completion of the treatment period, hapas were completely harvested. The total weight of fry, weight of a known number of fry, and the length distribution of fry was determined for each hapa. A random sample of 500-1000 treated fry was returned to each hapa for further growth. When the fry had reached about 5 cm in length, the gonads from about 200 fish were examined to determine the sex ratio using the aceto-carmine squash method described by Guerrero and Shelton (1974).

Maximum and minimum water temperatures were determined weekly at a depth of 0.5 m six days. The complete experiment was repeated seven times. Data were analyzed using ANOVA and regression analysis. Differences were declared significant at an alpha level of 0.05.

Results and Discussion

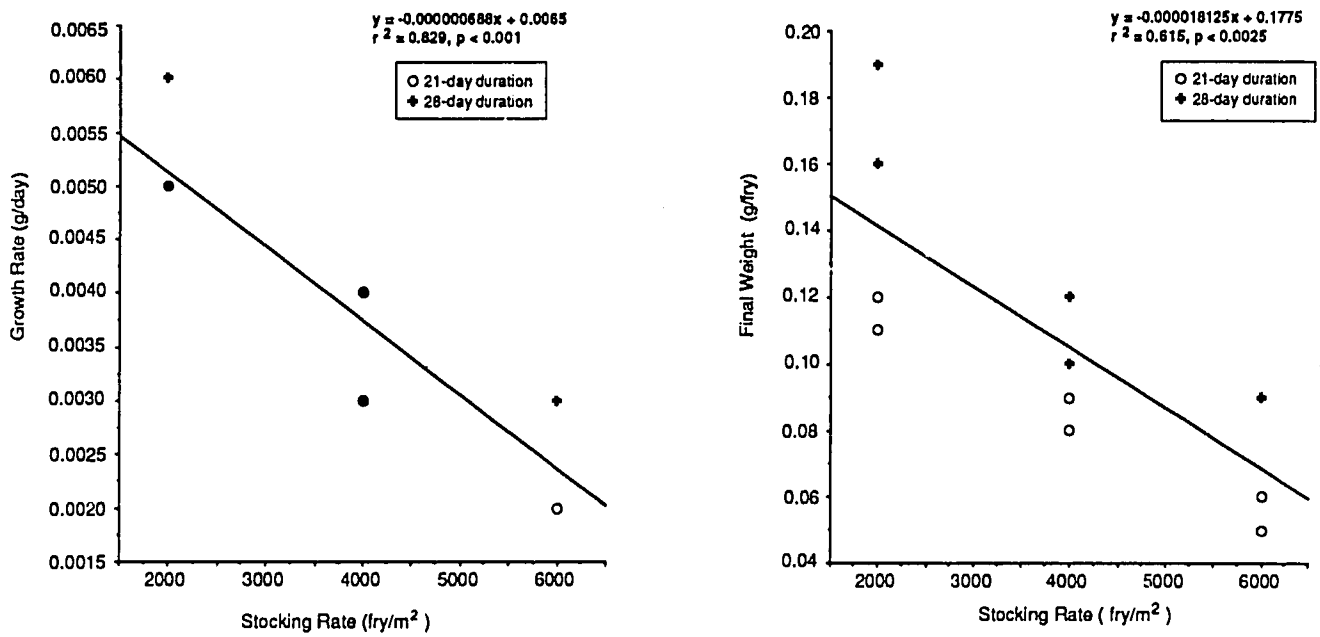
Sex reversal ranged from 98.3 to 100.0% males in all treatments, and was not significantly affected by the duration of hormone treatment or by the stocking rate (Table 1).

Table 1. Summary of sex reversal of *Oreochromis niloticus* in 1 m x 1 m x 1 m hapas (1.6 mm ace nylon mesh) for 21 or 28 days at three stocking rates in Honduras (n=2).

Trial	Duration (days)	Stocking rate (fry/m^2)	Initial weight (g/fry)	Initial length (mm/fry)	Final weight (g/fry)	Final length (mm/fry)	Survival (%)	Growth (g/day)	Males (%)
1	21	2000	0.011	8.9	0.120	18.9	38.5	0.005	99.1
1	21	4000	0.011	8.9	0.095	17.8	82.0	0.004	100.0
1	21	6000	0.011	8.9	0.075	15.9	78.5	0.003	100.0
1	28	2000	0.011	8.9	0.190	22.5	82.8	0.006	100.0
1	28	4000	0.011	8.9	0.120	19.4	84.5	0.004	99.9
1	28	6000	0.011	8.9	0.095	18.5	88.0	0.003	99.9
2	21	2000	0.013	9.6	0.130	19.6	114.5	0.006	99.0
2	21	4000	0.013	9.6	0.094	17.1	123.5	0.004	99.2
2	21	6000	0.013	9.6	0.040	16.1	109.0	0.002	98.3
2	28	2000	0.013	9.6	0.195	21.2	132.5	0.007	100.0
2	28	4000	0.013	9.6	0.110	17.6	113.5	0.004	100.0
2	28	6000	0.013	9.6	0.070	15.9	140.5	0.002	100.0
3	21	2000	0.013	9.2	0.115	18.5	102.6	0.005	100.0
3	21	4000	0.013	9.2	0.085	17.0	82.1	0.004	99.8
3	21	6000	0.013	9.2	0.055	15.2	102.6	0.002	100.0
3	28	2000	0.013	9.2	0.175	21.5	95.0	0.006	100.0
3	28	4000	0.013	9.2	0.110	18.4	97.1	0.004	100.0
3	28	6000	0.013	9.2	0.090	17.5	89.8	0.003	100.0
4	21	2000	0.015	9.4	0.150	20.9	44.3	0.006	100.0
4	21	4000	0.015	9.4	0.095	18.1	87.9	0.004	100.0
4	21	6000	0.015	9.4	0.085	17.0	91.1	0.004	100.0
4	28	2000	0.015	9.4	0.275	24.3	95.0	0.010	100.0
4	28	4000	0.015	9.4	0.195	21.0	79.0	0.007	100.0
4	28	6000	0.015	9.4	0.120	17.8	94.9	0.004	100.0
5	21	2000	0.016	9.6	0.200	21.6	39.3	0.009	100.0
5	21	4000	0.016	9.6	0.165	20.6	49.0	0.007	100.0
5	21	6000	0.016	9.6	0.115	18.9	27.4	0.005	100.0
5	28	2000	0.016	9.6	0.365	26.3	55.7	0.012	99.5
5	28	4000	0.016	9.6	0.160	21.9	44.0	0.005	99.5
5	28	6000	0.016	9.6	0.165	21.3	29.5	0.008	99.5
6	21	2000	0.017	10.1	0.105	17.5	111.0	0.005	99.8
6	21	4000	0.017	10.1	0.095	17.4	75.5	0.004	99.8
6	21	6000	0.017	10.1	0.070	15.8	77.0	0.003	100.0
6	28	2000	0.017	10.1	0.110	18.8	124.5	0.004	99.5
8	28	4000	0.017	10.1	0.112	18.9	86.5	0.004	100.0
6	28	6000	0.017	10.1	0.090	16.5	74.0	0.003	99.8
7	21	2000	0.015	10.0	0.130	18.2	58.5	0.006	99.7
7	21	4000	0.015	10.0	0.100	17.2	42.5	0.004	100.0
7	21	6000	0.015	10.0	0.075	17.2	39.0	0.003	100.0
7	28	2000	0.015	10.0	0.150	21.7	56.0	0.005	100.0
7	26	4000	0.015	10.0	0.120	19.1	60.6	0.004	100.0
7	28	6000	0.015	10.0	0.105	18.4	38.0	0.003	100.0

Survival was variable (Table 1), but did not significantly affect the effectiveness of the hormone treatment. In all experiments, tilapia survival did not differ significantly between treatment durations or among stocking rates. Two factors that probably influenced survival were the method of determining initial numbers of fry and water quality within the hapas. Although determining fry numbers by visual comparison is the least accurate method, it is the simplest method, and other, more accurate, methods require greater handling of fry and increased risk of fry mortality (Piper et al. 1983). Water quality deterioration was probably more influential in fry mortality. Hapas were located about 0.5 m apart, which may have restricted water exchange within hapas. Green (1988) reported that fry survival during sex reversal in 2 m^2 (surface area) hapas was 10% less than that in 5 m^2 hapas. The hapas used in this study had a surface area of 1 m^2.

There was no significant relationship between fry growth (g/day) and survival in any experiment. Fry growth, final fry weight, and final fry length were inversely related to stocking rate; results from Trial 3 are shown for illustrative purposes in Figure 1. The mean water temperature ranged from 23.5 to 28.5°C during the seven trials. The efficacy of hormone treatment was not affected significantly in this temperature range. Regression analysis (pooled data) indicated no significant relationship between growth rate and mean water temperature ($r^2 = 0.0005$, $p = 0.84$).



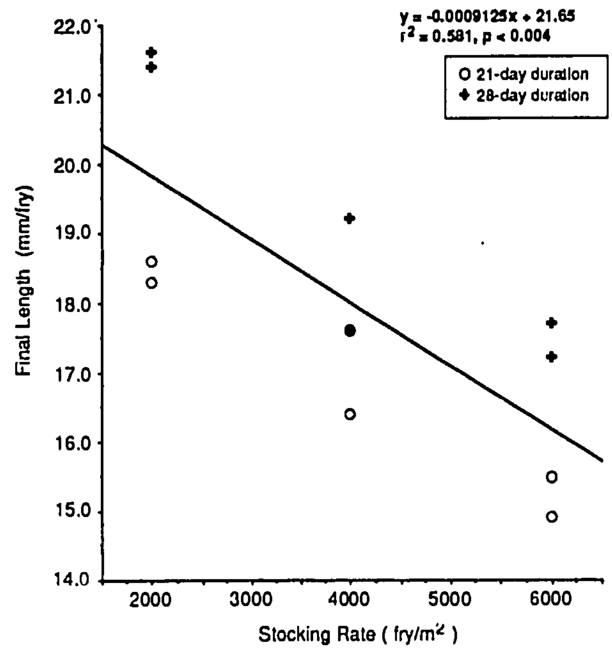


Figure 1. Relationship of *Oreochromis niloticus* fry growth rate, and final weight and length to stocking rate in 1-m² hapas during sex reversal Trial 3 in Honduras. Hormone treatment lasted 21 or 28 days.

Production of sex-reversed fry at El Carao could be increased by 34 to 70% over existing levels by increasing stocking rates and modifying the duration of treatment. Additional research is necessary to determine the relationship between fry survival and hapa surface area, and to determine if fry stocking rate can be further increased.

References

Green, B.W., 1988. Honduras freshwater aquaculture project final technical report. Auburn University, Alabama. 56 pp.

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

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler and J.R. Leonard, 1983. Fish hatchery management. U.S. Dept. of Interior Fish and Wildlife Service, Washington, D.C., 571 pp.

Production of *Oreochromis niloticus* Fry in Earthen Ponds for Hormonal Sex Reversal

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Introduction

Newly hatched *Oreochromis niloticus* (Nile tilapia) fry 9 to 11 mm in total length (TL) are preferred for hormonal sex reversal because they are presumed to be sexually undifferentiated. Oral administration of an androgenic hormone to these fish results in populations of fish composed of 97 to 100% males. In practice, the inclusion of fry up to 13 mm TL has not reduced the efficacy of hormone treatments. However, the treatment of fry greater than 13 mm TL is not as effective, and results in greater numbers of females after hormone treatment.

One method of fry production for sex reversal involves complete harvest of a reproduction pond 17 to 21 days after stocking and collection of the newly hatched fry. Observations made during preliminary fry production trials in Honduras indicated that the duration of the reproduction pond cycle necessary to produce 9- to 11-mm TL fry varied with water temperature. The ability to consistently produce sufficient numbers of fry for hormonal sex reversal is critical to maintaining fingerling supplies. The objectives of this study were:

1) to quantify fry production for sex reversal after 17- and 20-day reproduction pond cycles, and
2) to determine the effect of water temperature on fry production.

Materials and Methods

Eleven trials were conducted at the El Carao National Aquacultural Research Center, Comayagua, Honduras, between 20 January 1989 and 15 February 1990. Two 0.05-ha earthen ponds, each equipped with a 9-m^2 concrete harvest sump, were used for each trial. Two treatments (17- and 20-day cycles) were randomly assigned to ponds in each trial. Male and female *O. niloticus* broodfish were stocked in each pond on the same day. The ratio of females:males ranged from 1.9:1 to 2.5:1. The total weight of female broodfish ranged from 41.0 to 57.7 kg/pond and male broodfish ranged from 20.2 to 44.8 kg/pond. Maximum-minimum thermometers were suspended in each pond at a depth of 0.5 m, and temperatures were recorded (to the nearest 0.5°C) five days per week during all trials. Ponds were drained after 17 or 20 days. Outlets were covered with 1 mm square-mesh screen to prevent fry from escaping. Fry were harvested from the sump with dipnets (1.6 mm Ace nylon mesh). The number of fry was estimated by visual comparison with a counted sample. Fry from samples of 200 to 500 from each pond were measured for TL to the nearest mm. Fry were graded using a grader with 3.2-mm openings to separate them into groups ≤ 13 mm TL and > 13 mm TL. The total number and TL of fry retained by the grader was determined. All data were pooled and analyzed using an unpaired t-test and regression analysis. Differences were declared significant at an alpha level of 0.05.

Results and Discussion

The total number of fry harvested after the 17-day cycle (61,719 ± 18,745 fry/0.05 ha; mean ± SE) was not significantly different from the number harvested after 20 days (76,168 ± 17,563). At harvest, fry from the 17-day cycle averaged 9.5 ± 0.3 mm TL, not different from the 9.5 ± 0.1 mm TL mean for the 20-day cycle. There was a significant positive relationship between the total number of fry harvested and mean water temperature (Figure 1). However, the mean TL at harvest was independent of water temperature ($p > 0.05$, $r^2 = 0.067$). Fry greater than 13 mm TL were sometimes harvested from ponds. There was no significant relationship between the percent of fry retained by the grader and the mean water temperature for the 17-day cycle. The percent of fry retained by the grader increased significantly with increased water temperature for the 20-day cycle ($r^2 = 0.56$). No fry from the 20-day cycle were retained by the grader at mean water temperatures less than 25.0°C. The coefficient of determination (r^2) increased to 0.69 when data for temperatures < 25.0°C were excluded from the analysis. Retained fry averaged 14.5 ± 0.3 mm TL, and represented 4.7% of the total population.

No fry were harvested from 17-day cycle ponds in which the mean water temperature was less than 24.0°C (Figure 2). In 20-day cycle ponds mean water temperatures less than 23.6°C inhibited reproduction. Additional time was necessary for reproduction to occur at the lower temperatures. Mean water temperatures during these trials ranged from 22.7 to 27.8°C. Fry production would probably occur at the lower observed mean water temperatures if the cycle duration were increased. Likewise, the production of 9- to 11-mm TL fry could be maximized at the higher observed water temperatures if the cycle duration were further shortened. These questions require additional research.

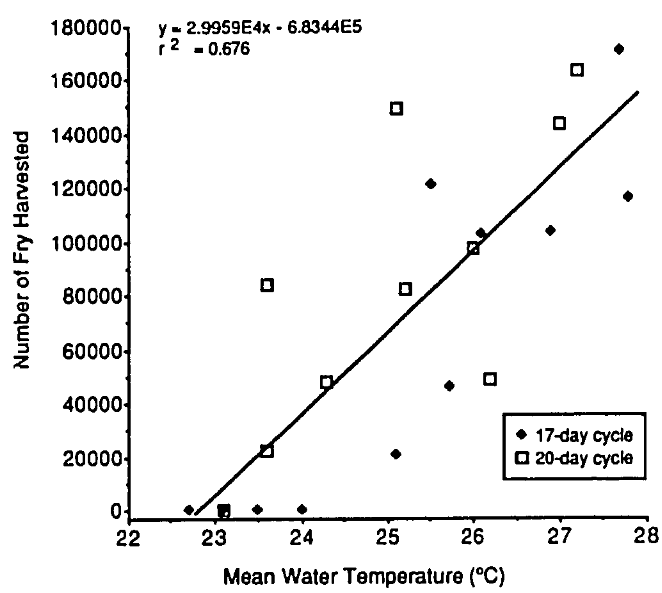
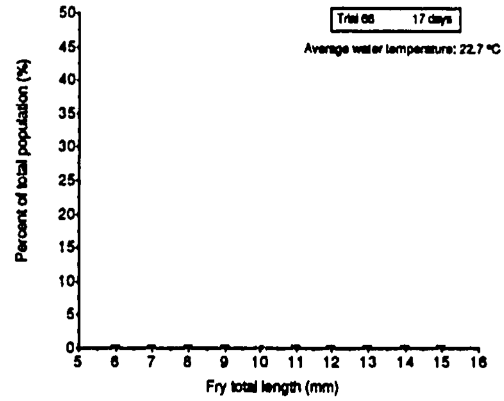
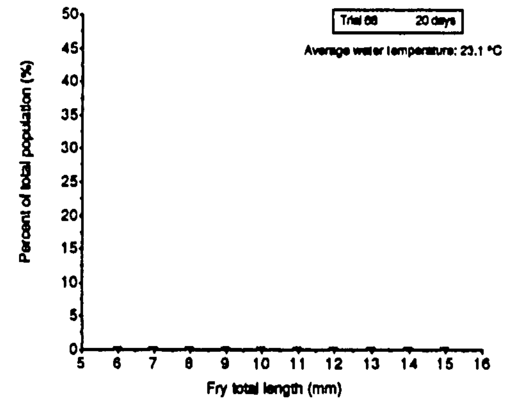
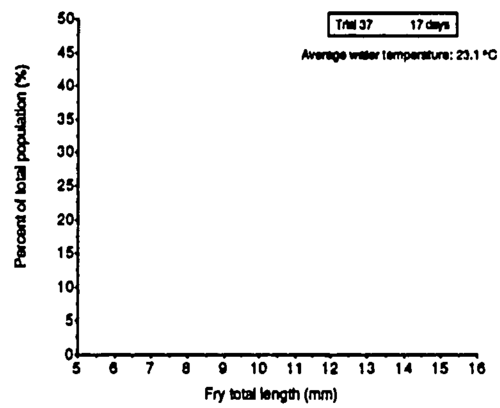
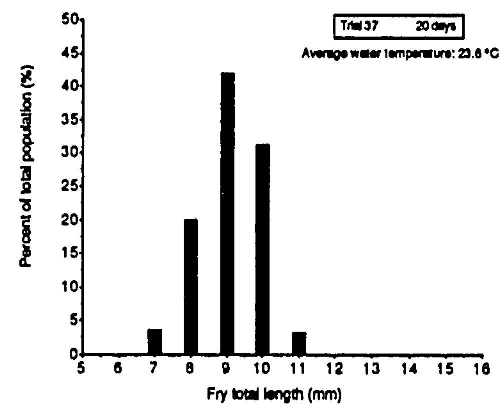


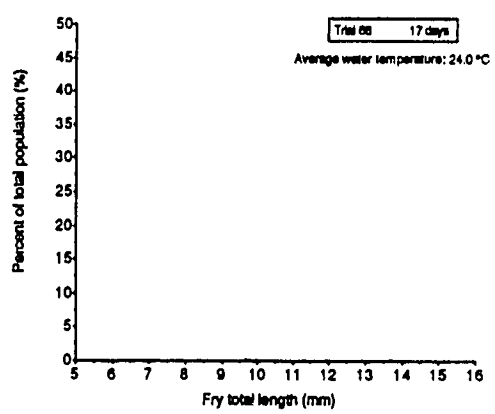
Figure 1. Relationship between the number of *Oreochromis niloticus* fry harvested and mean water temperature in Honduras. Earthen reproduction ponds (0.05-ha) were harvested 17 or 20 days after stocking.

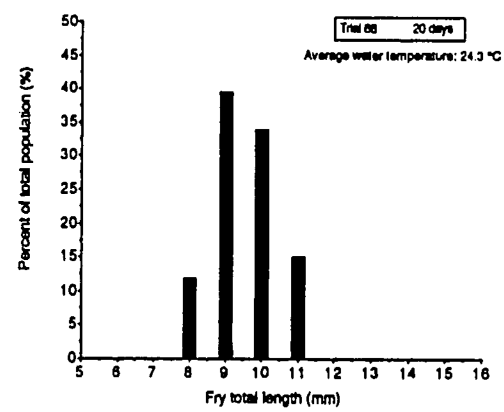

17 days
Average water temperature: 22.7 °C
Percent of total population (%)
Fry total length (mm)

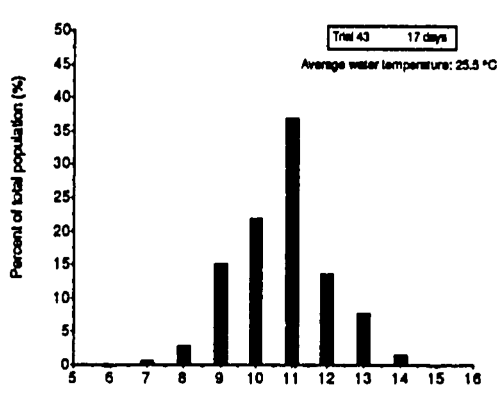

20 days
Average water temperature: 23.1 °C
Percent of total population (%)
Fry total length (mm)

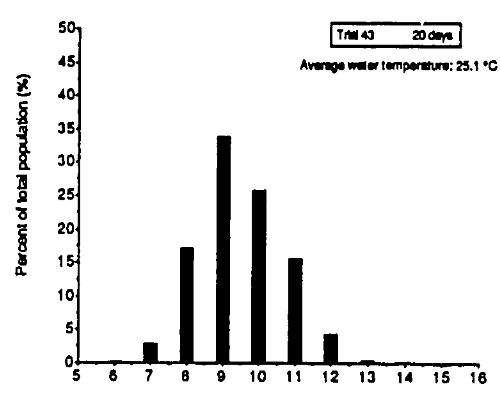

Trial 37 17 days
Average water temperature: 23.1 °C
Percent of total population (%)
Fry total length (mm)


Trial 37 20 days
Average water temperature: 23.6 °C
Percent of total population (%)
Fry total length (mm)


17 days
Average water temperature: 24.0 °C
Percent of total population (%)
Fry total length (mm)


20 days
Average water temperature: 24.3 °C
Percent of total population (%)
Fry total length (mm)


Trial 43 17 days
Average water temperature: 25.5 °C
Percent of total population (%)
Fry total length (mm)


Trial 43 20 days
Average water temperature: 25.1 °C
Percent of total population (%)
Fry total length (mm)

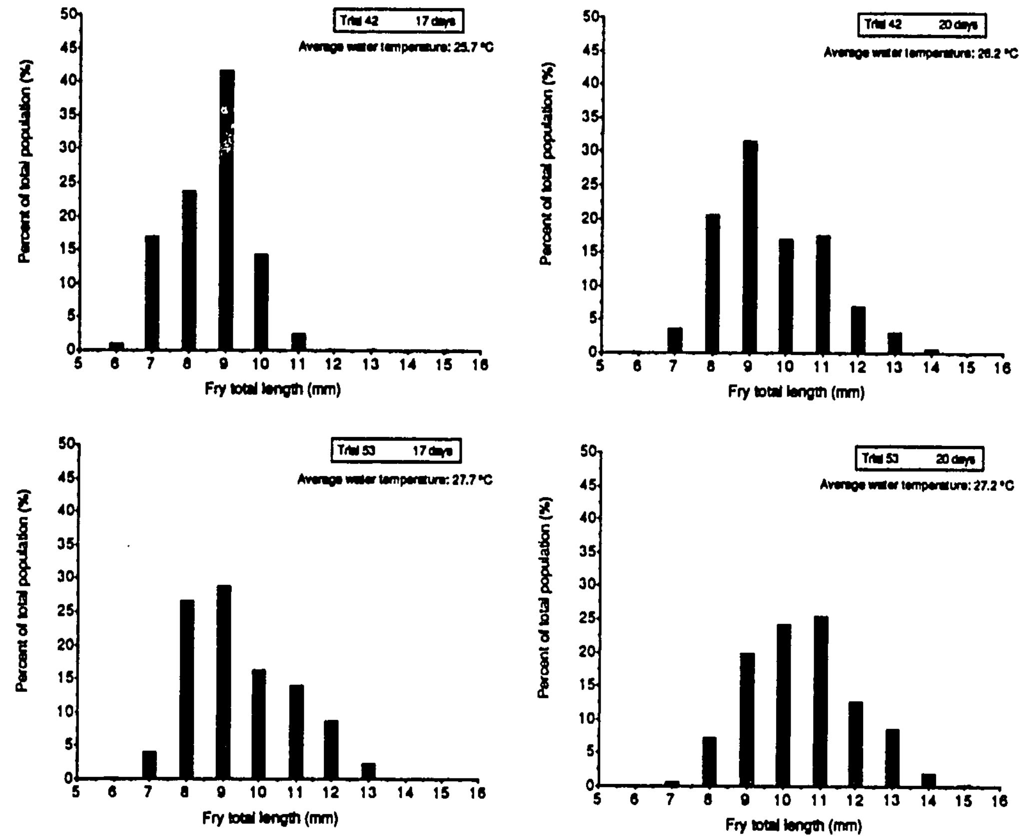


Figure 2. Size distribution of *Oreochromis niloticus* fry harvested from 0.05-ha earthen reproduction ponds 17 or 20 days after stocking in Honduras. Results are grouped by trial and mean water temperature.

Change of Fish Pond Soils During Culture and Drying Periods

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Introduction

The chemistry of pond water is mediated primarily by the chemistry of pond soils. Yet, few studies on changes in organic matter and chemical constituents of pond soils during culture and inter-culture periods (drying period) have been conducted, especially on a long-term basis. The most appropriate depth for obtaining soil samples for analyses that can be related to water column processes has also received little attention. The removal of bottom soils during the renovation of ponds at El Carao in January of 1990 presented an opportunity to begin a study of the evolution of pond soils, starting from a state similar to that of the soils in newly constructed ponds.

The objectives of this study were:

1) to quantify the accumulation of organic material and major nutrients such as phosphorus and nitrogen during the culture period,
2) to quantify the disappearance of organic material and major nutrients during pond drying,
3) to determine the depth of nutrient accumulation in soils, and
4) to begin a long-term study of pond soils at El Carao.

Materials and Methods

Six ponds were used in this study. During a 126-day culture period, all ponds were fertilized weekly with chicken litter at 750 kg total solids/ha, and three of the ponds were also fertilized weekly with urea at 10 kg N/ha. *Oreochromis niloticus* were stocked in all ponds at a density of 1 fish/m^2, and *Cichlasoma managuense* (guapote tigre) were stocked at a density of 0.025 fish/m^2 to control tilapia reproduction. Pond bottoms were divided into nine equal sections, and soil samples from each section were taken with a core sampler at the beginning of the season after ponds were filled, the day before harvest, and 2 and 37 days after harvest. The core samples were frozen in plastic tubes 4 cm in diameter and then divided into two sections: a 0-5 cm section and a 5-15 cm section. The samples were then oven dried at 65°C, ground, and stored in plastic bags to await analysis.

Results

Analysis of the soil samples has not yet been completed.

Optimization of Feeding in Combination with Organic Fertilization

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Introduction

Chicken litter is inexpensive relative to prepared feeds in Honduras, and can be used by producers as the sole nutrient input to achieve high production and a moderate profit (Green et al. 1990). Although higher profits can usually be realized by using feeds in place of chicken litter, the cost of the feeds may be prohibitive for many small farmers. The results of previous research have indicated that feeds are used more efficiently if they are combined with chicken litter fertilization. Litter is substituted for feed either by continuous applications or by sole use of litter during the first months of fish growth (Green 1988). The objectives of this experiment were:

1) to determine the effect of substituting chicken litter for feed on yield and profitability, and
2) to determine the effects of different feed and litter combinations on phytoplankton and zooplankton dynamics.

Materials and Methods

Four treatments were assigned to twelve 1000-m^2 ponds. The treatments were: 1) weekly applications of chicken litter at a rate of 1,000 kg/ha; 2) weekly applications of chicken litter at a rate of 1,000 kg/ha for the first month, followed by feeding; 3) weekly applications of chicken litter at a rate of 1,000 kg/ha for two months, followed by feeding; and 4) weekly applications of chicken litter at a rate of 1,000 kg/ha for three months, followed by feeding. Feed containing 25% crude protein was applied six days a week at 3% of fish biomass per day. All ponds were stocked with sex-reversed tilapia (*Oreochromis niloticus*) at 1 fish/m^2 and Guapote tigre (*Cichlasoma managuense*) at 450 fish/ha to control tilapia reproduction.

Water quality variables were monitored in two ponds each of Treatments 1, 2, and 4. Chlorophyll *a*, zooplankton (copepoda, cladocera, rotifera, and nauplii), and primary productivity were measured two times per week, and total phosphorus, filterable orthophosphates, total ammonia, and organic nitrogen were measure once per week. Total alkalinity, total hardness, and total and volatile solids were measured once a month. Wind speed, solar radiation, rainfall, and maximum and minimum air temperatures were measured daily.

Production data were subjected to partial economic analysis in which net income was the difference between gross income from the sale of fish and total costs of feed and chicken litter. Fish were sold at 4.40 Lempiras/kg, and the costs of feed and chicken litter were 1.14 Lempiras/kg and 0.08 Lempiras/kg, respectively. Data were analyzed by one-factor ANOVA, and differences were declared significant at an alpha level of 0.10.

Results and Discussion

There were no significant differences among treatments for water quality variables (Table 1). Yield and mean fish weight were significantly less in ponds receiving only chicken litter than in ponds receiving feed after one to three months (Table 1). Beginning feeding after one month, however, had no significant advantage over waiting three months to begin feeding. These results confirm those of earlier studies at El Carao, which have demonstrated that yields of tilapia can be increased by the use of feeds, but that feed use efficiency can be increased significantly by combining feeding with chicken litter fertilization.

Total costs increased as the length of time that ponds were receiving feed increased, and profitability increased as the ratio of chicken litter to feed increased (Table 2). Mean net income was significantly higher for ponds receiving only chicken litter or chicken letter with feed after three months, compared with ponds receiving feed after one or two months. These results demonstrate that no economic advantage is gained by feeding tilapia stocked at 1/m^2 if chicken litter is applied at high rates. An earlier study demonstrated, however, that net income of tilapia stocked at 2 fish/m^2 was approximately double that of tilapia stocked at 1 fish/m^2, when feeding was begun after two months of fertilization with chicken litter.

Table 1. Treatment means (± SE) of water quality variables measured in tilapia ponds receiving only weekly applications of chicken litter at 1000 kg total solids/ha (CL), or applications of chicken litter for 1 (CL/1MO) or 3 (CL/3MO) months followed by feeding with a 25% protein pellet. N=2 for each treatment.

Treat	Organic nitrogen (mg/l)	Total ammonia-N (mg/l)	Total phosphorus-P (mg/l)	Chlorophyll a (µg/l)	Rotifera (No./l)	Cladocera (No./l)	Copepoda (No./l)
CL	4.24 ± 0.24	0.08 ± 0.004	7.87 ± 0.28	454 ± 27.8	4410 ± 1500	32 ± 25.3	622 ± 105
CL/1MO	4.05 ± 0.07	0.11 ± 0.004	6.42 ± 0.80	456 ± 95.4	3274 ± 898	10 ± 8.6	780 ± 69
CL/3MO	4.20 ± 0.16	0.12 ± 0.02	7.80 ± 0.58	474 ± 39.4	6111 ± 1667	36 ± 29.4	686 ± 35

Table 2. Yield and profitability (± SE) of tilapia culture using only weekly applications of chicken litter at 1000 kg total solids/ha (CL), or applications of chicken litter for 1 (CL/1MO), 2 (CL/2MO), or 3 (CL/3MO) months followed by feeding with a 25% protein pellet.

Treatment	Gross Yield (kg/ha)	Mean harvest weight (g)	Survival (%)	Total Cost (Lps./ha)	Net Income (Lps./ha)
CL	1779 ± 80.0 [a]	206 ± 9.1 [a]	86 ± 0.1	1785	6042 ± 352.0 [a]
CL/1MO	2349 ± 142.0 [b]	276 ± 16.2 [b]	85 ± 3.0	6520	3814 ± 624.7 [b]
CL/2MO	2196 ± 100.7 [b]	256 ± 8.6 [b]	85 ± 1.2	5828	3835 ± 443.1 [b]
CL/3MO	2223 ± 170.4 [b]	258 ± 16.7 [b]	86 ± 2.0	4700	5079 ± 749.6 [a]

[a,b] Means followed by the same letter are not different ($P < 0.10$).

References Cited

Green, B.W., D.R. Teichert-Coddington, and R.P. Phelps. 1990. Response of tilapia yield and economics to varying rates of organic fertilization and season in two Central American countries. Aquaculture 90:279-290.

Green, B.W. 1988. Honduras Freshwater Aquaculture Project Final Technical Report. Auburn University, AL. 56 pp.

Relative Influence of Feed and Organic Fertilization on Polyculture of Tambaqui and Tilapia

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Introduction

Information on the comparative growth characteristics of tilapia and tambaqui is limited, especially in light of the importance of each as an aquaculture species. In Panama, CRSP researchers compared growth of the two species in monoculture under pellet-fed conditions. In Honduras, the principal culture species is tilapia, but there is interest in knowing how tambaqui might grow with tilapia under conditions that usually do not include a high quality diet. The objective of this experiment was to test the growth of tambaqui in polyculture with tilapia in ponds receiving chicken litter or chicken litter and a supplemental commercial diet.

Materials and Methods

Six 1000-m^2 ponds were stocked with fingerlings of sex-reversed tilapia (*Oreochromis niloticus*) at 1 fish/m^2, tambaqui (*Colossoma macropomum*) at 0.15 fish/m^2, and guapote tigre (*Cichlasoma managuense*) at 0.025 fish/m^2 to control tilapia reproduction through predation. Three of the ponds were fertilized weekly with chicken litter at 1000 kg total solids/ha for the first six weeks, and at 750 kg total solids/ha for the remainder of the study. The remaining three ponds were fertilized weekly with chicken litter at 500 kg/ha, and were supplemented with a 25% protein feed at about 1.5% of tilapia biomass per day, six days a week. Fish were sampled at monthly intervals and were harvested on 19 June 1990, 126 days after stocking.

Data were analyzed by unpaired t-tests. Differences were declared significant at an alpha level of 0.05. The null hypothesis was that tambaqui and tilapia growth would not be improved by supplementing organic fertilization with a pelleted commercial feed.

Results and Discussion

The mean weights of tilapia and tambaqui, and the mean gross yield of fish were significantly greater in fed ponds (Table 1). Tambaqui were 422% larger in fed ponds than unfed ponds, whereas tilapia were only 39% larger in fed ponds. Tambaqui benefited to a greater extent from the commercial pellet than did tilapia. Tambaqui grew little and did not reach a marketable size in unfed ponds, which confirms that a high quality diet is necessary for their culture. Higher stocking rates of tambaqui would probably have increased total production in the fed ponds without reducing tilapia growth, although the optimal stocking ratio is not known. Although the cost of feed was much higher than the cost of chicken litter, the net income for combined fish yield from fed ponds was significantly higher than that from unfed ponds. The practical implications of this study are that producers should not stock tambaqui if they are unwilling or unable to invest in a supplemental commercial diet.

Table 1. Pond and treatment means for fish production during a 126-day growth trial of tilapia (*Oreochromis niloticus*) and tambaquí (*Colossoma macropomum*). Ponds were stocked with tilapia (1 fish/m^2) and tambaquí (0.15 fish/m^2), and treated with chicken litter or chicken litter plus a commercial diet. The initial weights of tilapia and tambaquí were 13.1 g and 40 g, respectively.

		Tilapia at Harvest			Tambaqui at Harvest			Yield of tilapia	Net Income
Treatment	Pond	Mean wt. (g)	Gross yield (kg/ha)	Survival (%)	Mean wt. (g)	Gross yield (kg/ha)	Survival (%)	& tambaqui (kg/ha)	(Lempiras/ ha)
Manure Only	B2	177.2	1513.0	86.1	131.1	108.8	55.3	1621.8	5861
Manure Only	B7	147.2	1165.6	79.0	88.4	84.9	64.0	1250.5	4227
Manure Only	B8	177.3	1387.2	77.8	37.1	34.1	61.3	1421.3	4979
	Mean	167*	1355*	81*	86*	76*	60	1431*	5022*
	Stand Error	10.0	101.5	2.3	27.2	22.0	2.60	107.3	472.1
Manure+Feed	B4	251.9	1995.2	79.2	311.7	221.3	47.3	2216.5	6684
Manure+Feed	B6	242.7	1911.4	78.7	474.6	370.2	52.0	2281.5	6971
Manure+Feed	B11	201.5	1857.7	92.2	553.6	459.5	55.3	2317.7	7130
	Mean	232*	1921*	83*	447*	350*	52	2272*	6928*
	Stand Error	15.5	40.00	4.4	71.2	69.5	2.3	29.6	130.3

* Differences between treatment means are significant ($P \leq 0.05$).

Benthic Respiration in Newly Renovated Ponds

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Introduction

In-situ benthic respiration is difficult to measure, because the pond bottom must be isolated from the column of water for a sufficient amount of time to measure change, and because high variation found over the pond bottom dictates that many subsamples must be obtained in order to increase confidence in the average. Benthic respiration can be expected to change with depth, which ranges from relatively deep at the drain end to shallow at the opposite end, and with time, over the duration of a culture period.

Benthic respiration has been estimated at El Carao by measuring the change in dissolved oxygen concentrations in PVC tubes implanted in the pond bottom over a period of time. This method shows potential for regular use, because it is straightforward and is not excessively time-consuming. However, the numbers of subsamples necessary to obtain a good pond average, the optimum location of tubes in the pond, and the optimum frequency of sampling during the culture period are unknown. Knowledge of these aspects would increase the efficient use of time and resources, and enable workers to make more informed inferences from respiration data.

The objectives of this study were:

1) to determine the relative amount of variation in benthic respiration found within and between ponds,
2) to determine the variability of respiration over time in newly renovated ponds, and
3) to relate benthic respiration to soil organic matter content, which was measured during a related soils study.

Materials and Methods

Three ponds were used in this study. During 126 days of culture, ponds were fertilized weekly with chicken litter at 750 kg total solids/ha. The pond bottoms were divided into nine equal sections, and benthic respiration was measured in each section on each sampling date. Benthic respiration was estimated for a 24-h period by measuring the change in dissolved oxygen in a tube of well water implanted on the pond bottom. The tube was made of three-inch diameter PVC pipe fitted with a PVC cap that prevented the entrance of light or air during the sampling period. The pipe was filled with well water prior to placement on the bottom and the water level was adjusted to that of the pond to avoid seepage into or out of the pipe. Well water was used to minimize sources of respiration other than benthic. Respiration in all tubes was corrected against a control tube of well water that was installed in each pond. Dissolved oxygen was measured in tubes at 20-cm intervals at the beginning and end of the measurement period, which lasted approximately 24 hours.

Results

Benthic respiration increased from a mean of 1.65 $\mu g\ O_2/cm^2/h$ at the beginning of the season to 2.68 $\mu g\ O_2/cm^2/h$ by mid season, as pond muds became populated by oxygen consuming organisms and pond fertility increased (Table 1). After mid-season, respiration decreased to a low of 1.19 $\mu g\ O_2/cm^2/h$ by the end of the season, probably because of continually low dissolved oxygen near the bottom. The effect of pond depth on respiration could not be ascertained, because respiration was more closely associated with distance from the point of fertilization. Chicken litter was applied on the windward side of ponds, which was usually the same every week because of prevailing winds. Consequently, the area of each pond closest to the point of dispersal received more chicken litter and had correspondingly higher rates of respiration than the rest of the pond. The mean respiration rates for the sections closest to, midway, and farthest from the primary dispersal site were 2.44, 1.80, and 1.36 µg $O_2/cm^2/h$, respectively. Soil analyses have not been completed, so the relationship between respiration and organic matter content of pond soils could not be ascertained.

The variability of respiration was greater within ponds than among ponds. Coefficients of variation ranged from 23 to 128 within ponds, and from 6 to 46 among ponds. High variability within ponds indicates that more subsamples are required to confidently establish a pond mean than is practical.

Table 1. Mean benthic respiration ± standard deviations (SD), and coefficients of variation (CV) measured 5 times in three ponds during a 126-day culture period. Nine sections within each pond were sampled on each sampling date.

	Mean ± SD (µg $O_2/cm^2/h$)						
Pond	28 Feb 90	22 Mar 90	18 Apr 90	30 May 90	13 Jun 90	Pond mean	Range of CV
B1	1.72 ± 1.100	2.40 ± 1.074	2.98 ± 1.063	2.14 ± 0.676	1.66 ± 1.838	2.18	32 - 111
B9	1.59 ± 1.345	1.23 ± 1.574	2.34 ± 0.849	1.58 ± 0.367	1.05 ± 0.907	1.56	23 - 128
B10	-	-	2.74 ± 1.738	2.45 ± 0.987	0.86 ± 0.797	2.02	40 - 93
Mean ± SD	1.65 ± 0.091	1.81 ± 0.832	2.68 ± 0.324	2.06 ± 0.442	1.19 ± 0.416	1.92 ± 0.32	
CV	6	46	12	21	35	17	

Rwanda Technical Reports

The Influence of Composting Regimes and Stocking Density on Mixed-Sex Tilapia Production

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Introduction

In-pond composting of various mixtures of grasses, leaves, and manures forms the basis of tilapia production systems used throughout rural Africa. Although it is generally accepted that the application rates of inorganic fertilizers should either increase or remain constant over a production cycle, the possible slow decomposition time of organic fertilizers such as composted grasses suggests that high initial application rates may be beneficial to fish production. This benefit may be especially great in mixed-sex tilapia culture, where an early high growth rate of fish is to be encouraged to compensate for later low growth rates of females due to reproduction.

Optimal stocking rates for tilapia depend on the market values of particular sizes of fish, the type of pond management to be practiced (mixed-sex or monosex; fertilization and feeding regimes), the size and age of fish to be stocked, and the productive capacity of the pond environment.

Objectives

The objectives of this experiment were:

1) to assess the growth and production of male and female *Oreochromis niloticus* (Nile tilapia) fingerlings stocked at different densities, and
2) to test two organic fertilizer application regimes: a large amount applied at the beginning of the production cycle followed by smaller weekly applications of 10% of the initial amount (HI), versus a constant weekly application (CONST). The HI approach is currently recommended by the Rwandan Fish Culture Extension Service.

Materials and Methods

Each of nine 7-are (0.07-ha) ponds was filled and fertilized with 230 kg (dry weight) of a 4:1 mixture of freshly cut grasses from pond levees and chicken litter between 10 and 13 October 1989. About 10% of this amount was added to each pond weekly thereafter (composting regime HI). Nine other 7-are ponds each received the same grass/chicken litter mix (4:1 ratio) at a constant rate of 500 kg/ha/wk (dry weight) (composting regime CONST). Dry weights of the inputs were measured each week to adjust the input quantities for the following application. A total of about 700 kg (dry weight) was added per pond for all treatments (10 T/ha over 20 weeks). Each fertilizer regime was tested in three ponds, which were stocked with 350, 700, or 1400 mixed-sex, advanced juvenile *O. niloticus* averaging 45 g.

Fish were sampled monthly, separated by sex, counted, and weighed. Morning and afternoon dissolved oxygen levels were measured daily for three weeks following the first fertilizer application and weekly thereafter. Uncorrected chlorophyll *a* was measured every two weeks; all other parameters were measured as directed in the CRSP Fourth Work Plan.

Results

Ponds receiving the high initial application of compost had significantly lower morning dissolved oxygen levels during the first three weeks of the experiment (average 1.7 mg/L) than did ponds receiving the constant compost application (average 3.8 mg/L). Significant differences in chlorophyll *a* levels were observed among the three stocking rates but not between the two composting regimes. Ponds with stocking rates of 1 and 2 fish/m^2 had the highest levels (57.7 and 51.3 mg/m^3 respectively), followed by ponds stocked at the 0.5 fish/m^2 rate, which had a significantly lower average chlorophyll *a* level (38.0 mg/m^3).

There was little difference between the growth rates of fish of either sex in the two compost application regimes during the first two months. However, after the second month, the growth rate of fish stocked at 2/m^2 was notably lower in ponds receiving the high initial compost input rate than in ponds receiving the constant rate. The growth of males decreased with stocking density at a rate greater than that of females (Figure 1). The slopes of these lines differed by a factor of two. At the highest densities, many of the adult females were about the same size as the larger fingerlings produced.

Fingerling production per female was highest (9.8) at the low fish stocking density, probably because of the higher average weight of the females at this low density. The total number of fingerlings produced averaged 1541, 1837, and 1411 fingerlings per pond for the 0.5, 1, and 2 fish/m^2 densities, respectively.

The high initial application of compost resulted in lower total production than the constant application rate, probably as a result of reduced nutrient inputs towards the end of the experiment. The high initial rate did not result in greater primary production at the beginning of the experiment, probably because of the resulting reduction in dissolved oxygen which could inhibit plankton production.

The growth of male fish was hindered more than that of female fish as stocking densities increased. No ponds yielded enough fingerlings larger than 5 g to allow for restocking at the same density. Average net production, including the weight of fingerlings, was highest for the stocking density of 1 fish/m^2, followed by 2 fish/m^2 and 0.5 fish/m^2. The production difference between the 1 fish/m^2 and 2 fish/m^2 densities was mostly due to differences in reproduction (Figure 2).

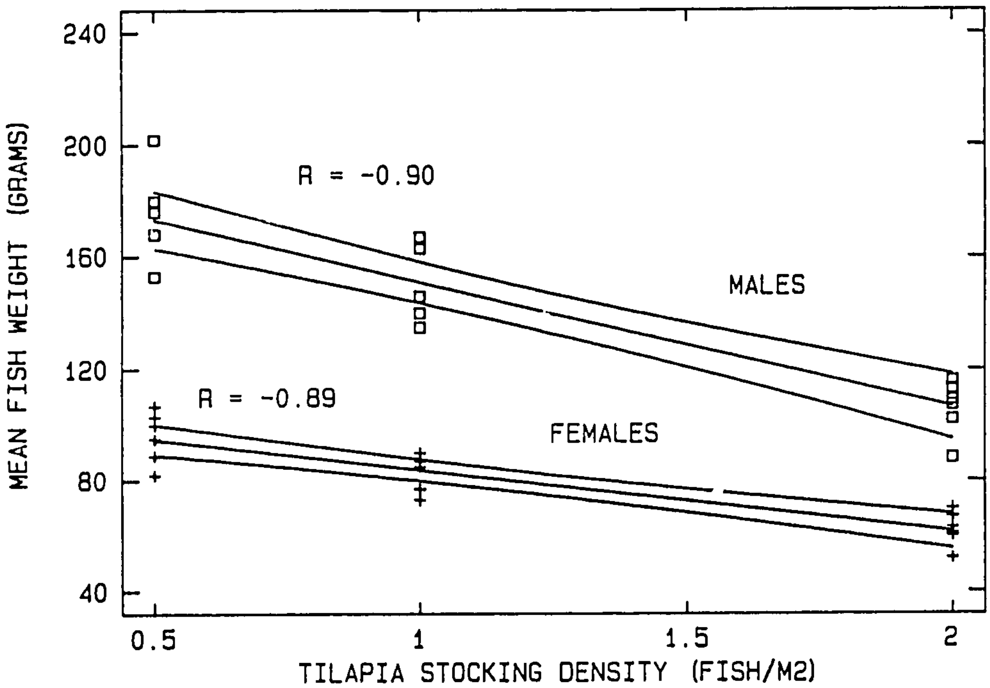

Figure 1. Mean weight of male and female tilapia (*Oreochromis niloticus*) in relation to stocking density.

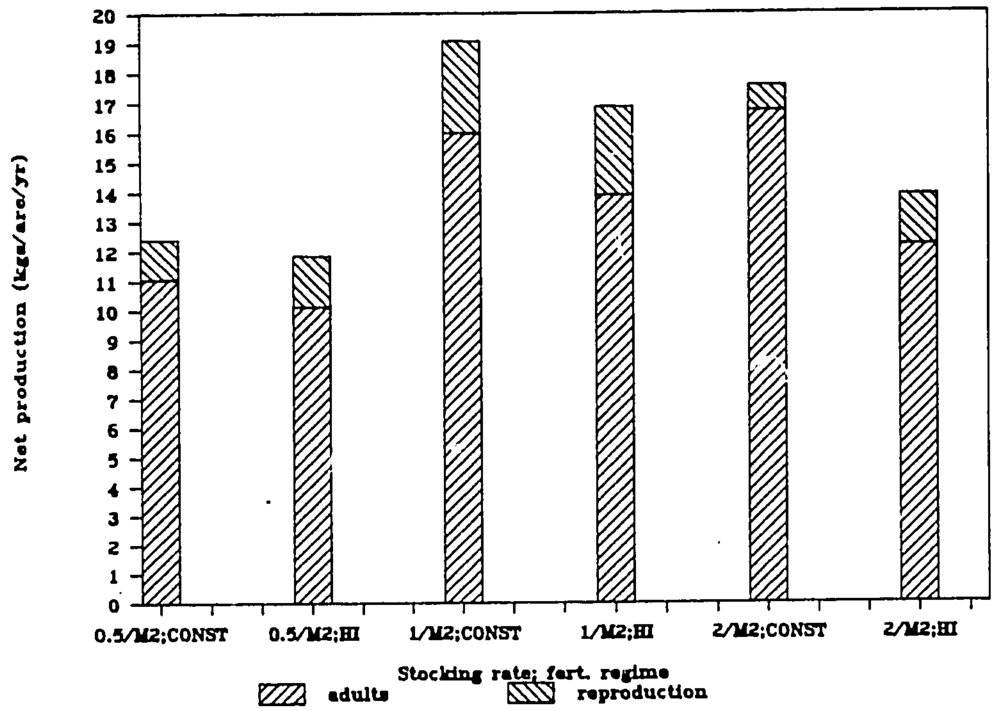

Figure 2. Production of adult and fingerling tilapia (*Oreochromis niloticus*) under two pond fertilization regimes—high initial (HI) and constant (CONST)—and at three stocking densities.

Anticipated benefits

This experiment was the first CRSP experiment using mixed-sex tilapia and inputs similar to those used in rural areas of Africa. These results suggest appropriate fish stocking densities and compost addition procedures. In the absence of supplemental feeding, increasing stocking densities beyond about 1.0 fish/m^2 does not increase production. The proper application of scarce organic inputs will increase fish production and economic efficiency and conserve resources for rural African farmers.

Rwanda Rural Pond Survey

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Introduction

There are about 3,000 fish ponds in operation in Rwanda, most of which are managed by groups of farmers or individual families. Most of the ponds are in the mid-elevation zones of the country, i.e., at elevations between 1500 and 1700 m. Only a few ponds are found at higher elevations, because the extension service has not encouraged tilapia culture at elevations above 2000 m. Given the low quality and quantity of inputs used by most farmers, researchers have hypothesized that low water temperature is not the primary constraint to tilapia production in Rwanda, but that the management of inputs and water can be improved before the temperature constraint becomes important (Hishamunda and Moehl Jr. 1989).

Objectives

The objectives of this study were:

1) to locate similar ponds at different altitudes for inclusion in the field trials proposed for Study 3;
2) to find inputs of similar quality available to farmers at all altitudes for the field trials of Studies 3 and 4;
3) to gather data on the pond management practices currently used by farmers and the resulting levels of production; and
4) to contribute to the CRSP global model by furnishing information on management practices used in high-altitude tropical environments in developing countries.

Materials and Methods

During the period from February through June, 1990, visits were made to 21 marais having multiple ponds. A total of 280 ponds were present in these areas and 67 ponds were examined in detail. Pond water and canal water samples were taken and analyzed for alkalinity, hardness, pH, and conductivity. Water temperatures and dissolved oxygen levels were also noted for ponds and inlet canals. Soil samples were taken from the bottoms and levees of some ponds. Farmers were interviewed as to their interest in participating in field trials, the types of inputs they use and have available, and whether they had been included in either of two previous studies– those conducted by Molnar et al. (1990) and by Engle et al. (1990). Where records were available, total fish production, size of fish, and length of growing cycle were noted. An altimeter was used to determine elevation, and topographic maps (1:50,000) were used to verify locations and elevations.

Results

Low (1350 to 1500 m ASL) and medium elevation (1500 to 1700 m ASL) ponds showed little difference in measured parameters but varied greatly in reported yields, with net annualized production ranging from 900 to over 4000 kg/ha/yr. From 20 to 50% of the total weight harvested was in the form of fingerlings (reproduction); the higher percentages occurred when the production cycle exceeded seven months. Production cycles of five to seven months were most common, however. Farmers obtaining low net production explained that they had previously obtained very high production with their first pond and consequently constructed several additional ponds, only to spread out the limited inputs they had available.

Production cycles at the highest elevations (1900-2200 m) ranged from 10 to 24 months. Net annualized production was reported to be generally about 1500 ± 400 kg/ha/yr. At the 1900 m elevation, reproduction was not substantial but did provide enough fingerlings for pond restocking and, in some cases, a slight excess for sale to other farmers. Above 2000 m, low fingerling production was considered a major constraint; only one pond produced more than 100 fingerlings and no ponds ever produced enough for restocking at more than 0.5 fish per m^2. Stocking rates were low because of the lack of fingerlings and this is a possible cause of the low net production. Average size of fish at harvest was usually well over 200 g. Curiously, water management was very poor at the highest elevations and ponds often had continuous water inflow, often from canals with water temperatures of less than 15°C. Farmer interest was remarkably high at the higher elevations, probably because of the lack of extension services in these locales and a resulting unrealistically high expectation of potential production. Another reason for the high interest was that the fish ponds provided greater revenues per unit area than traditional agriculture.

Inputs consisted mostly of tender green leaves as feed, with grasses and some assorted manures as fertilizers. Some farmers fed sorghum beer waste and many used banana peels left over from banana beer production as fertilizer.

Anticipated benefits

Data collected will be of value in the development of the DAST expert system for pond management. The Rwanda National Fish Culture Extension Service has benefited from the observations made by the CRSP researchers, and farmers have been very receptive and appreciative of the site visits.

Literature Cited

Engle, Carole. 1990. An economic analysis of aquacultural production technologies in Rwanda. Pages 28-29 *in* Pond Dynamics/Aquaculture CRSP Seventh Annual Administrative Report. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

Hishamunda, Nathanael and John S. Moehl, Jr. 1989. Rwanda National Fish Culture Project. Research and Development Series #34. International Center for Aquaculture, Auburn University, Alabama.

Molnar, Joseph J., Rubagumya, Alfonse, and Vewonyi Adavon. 1990. Sustainability of aquaculture as a farm enterprise: Impacts and consequences of fish culture in Rwanda. Joint Meeting of the South and North Central Sociological Society. Louisville, Kentucky.

Production of *Oreochromis niloticus* as a Function of Organic Matter Application Rates and Supplementation with Inorganic Nitrogen and Phosphorus Fertilization

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Introduction

Previous experiments showed that higher tilapia production results from the direct application of fresh grasses to the pond (in-pond composting), as opposed to preliminary out-of-pond composting. However, the optimum rates of compost application were not determined. Fresh leaves of *Titonia* *diversifolia* (Compositae) are added to many family fish ponds in Rwanda and Zaïre, along with grasses, as compost. The leaves are said to decompose readily, but their value as a fertilizer or feed has not yet been studied.

Objectives

The objectives of this experiment were:
1) to determine the optimum loading rate of an 80:20 mixture of fresh grass and chicken litter, and
2) to determine the effect of supplementing the mixture with inorganic nitrogen or phosphorus.

In addition, the growth rate of tilapia in ponds receiving weekly applications of fresh leaves was compared with growth in ponds receiving the same quantity of nitrogen in the form of organic inputs.

Materials and Methods

Eighteen 7-are ponds at the Rwasave Fish Station were used in a 6x3 experimental design. Treatments 1, 2, and 3 consisted of 500, 750, and 1000 kg/ha/wk, respectively, of an 80:20 mixture of grasses freshly cut from pond levees and chicken litter. Ponds in Treatment 4 received the same organic inputs as Treatment 1 plus additional nitrogen as urea to bring the total N to double that of Treatment 1. Ponds in Treatment 5 received the same inputs as Treatment 1 plus additional phosphorous in the form of TSP (triple superphosphate) to double the total amount of P in Treatment 1. Treatment 6 consisted of tender green leaves of *T. diversifolia*. The application rate for *T. diversifolia* was calculated to give the same amount of N as Treatment 1. Treatments 1 to 6 are hereafter described as "500", "750", "1000", "500+N", "500+P", and "TITON", respectively.

Fertilization of the ponds began ten days prior to stocking. Amounts were adjusted weekly or monthly based on running averages of dry weight and N and P levels in the inputs. Each pond was stocked with 380 male *Oreochromis niloticus* (Nile tilapia) averaging 42 g. The culture period was 144 days. Dissolved oxygen (DO) concentrations were measured weekly in the morning (0630 to 0730 hours) and afternoon (1530 to 1630 hours) in all ponds. Uncorrected chlorophyll *a* was measured from a combined 90-cm water column every two weeks for the duration of the experiment. All other procedures followed standard CRSP protocol.

Results

The results of this experiment are summarized in Table 1. The parameter that best predicted net fish production was the weekly measure of dissolved oxygen in the morning and afternoon. Afternoon minus morning DO at 25 cm was strongly correlated with net fish production ($r = 0.7$) (Figure 1), whereas chlorophyll *a* levels were not as strongly correlated with fish production ($r = 0.53$). The average chlorophyll *a* content was similar in ponds receiving treatments of organic matter not supplemented with inorganic fertilizers, but fish yield was lowest in the "1000" treatment. The major outliers in the chlorophyll *a*-fish production correlation were ponds receiving the highest carbon loading (treatment "1000") and a pond from treatment "500+N" in which a partial fish kill resulted in recovery of only 79% of the fish stocked. Chronically low DO levels probably contributed to the low growth rate of fish in the "1000" treatment.

Doubling the nitrogen in the "500" treatment by adding an equivalent amount of N in the form of urea (treatment 500+N) resulted in significantly improved growth (168 vs 201 g final average weight), as did supplementing the "500" treatment with inorganic P (treatment 500+P) (168 vs 203 g final average weight) (Figure 2). Because the prices of urea and TSP in Rwanda are subsidized, it proved especially economical to add inorganic P to the compost. However, the increased risk of plankton dieoffs resulting from the addition of urea to high organic loading levels leads to some reservations in recommending this fertilization regime.

The *T. diversifolia* leaves have a crude protein content of 25 to 30% (dry matter basis) and are consumed directly by the fish. However, much of the potential feedstuff was not consumed because relatively large quantities were added infrequently (weekly). Primary productivity and fish production were lowest in this treatment.

Anticipated benefits

The results of this experiment have already benefited extension services in Rwanda and Burundi. As a general rule, 5-7 kg dry weight/are/wk is the maximum input rate for low quality organic matter such as fresh grasses. Additional loading may lead to a reduction in fish survival and growth. Where the quantity of grass available is less than the amount recommended, fresh vegetable matter may be supplemented with inorganic nitrogen and/ or phosphorus to increase fish production.

Table 1. Fertilization inputs, chlorophyll *a* concentration, difference in morning and afternoon dissolved oxygen concentrations, and tilapia survival, weight, yield, and production.

	TREATMENT					
	500	750	1000	500+N	500+P	TITON
Inputs						
Fresh grass	400	600	800	400	400	0
Chicken litter	100	150	200	100	100	0
Leaves	0	0	0	0	0	270
Urea	0	0	0	28.6	0	0
TSP	0	0	0	0	9.4	0
Input C:N	16:1	16:1	16:1	16:2	16:1	17:2
Input N:P	4.8:1	4.8:1	4.8:1	9.6:1	2.9:1	15.6:1
Input C:N:P	77:5:1	77:5:1	77:5:1	77:10:1	46:3:1	136:16:1

Table 1. (continued)

	TREATMENT					
	500	750	1000	500+N	500+P	TITON
Water Quality						
Chl *a* (mg/m^3)	94	72	99	269	141	51
$D.O._{pm}$-$D.O._{am}$ (mg/L)	6.8	5.2	3.25	10.3	7.4	4.0
Fish						
%survival	95.6	97.8	91.3	79.0	95.1	95.4
Mean weight (g)	168	179	141	201	203	150
Net yield (kg/ha)	674	645	419	694	752	487
Net prod.(kg/ha/yr)	1709	1636	1063	1759	1907	1234

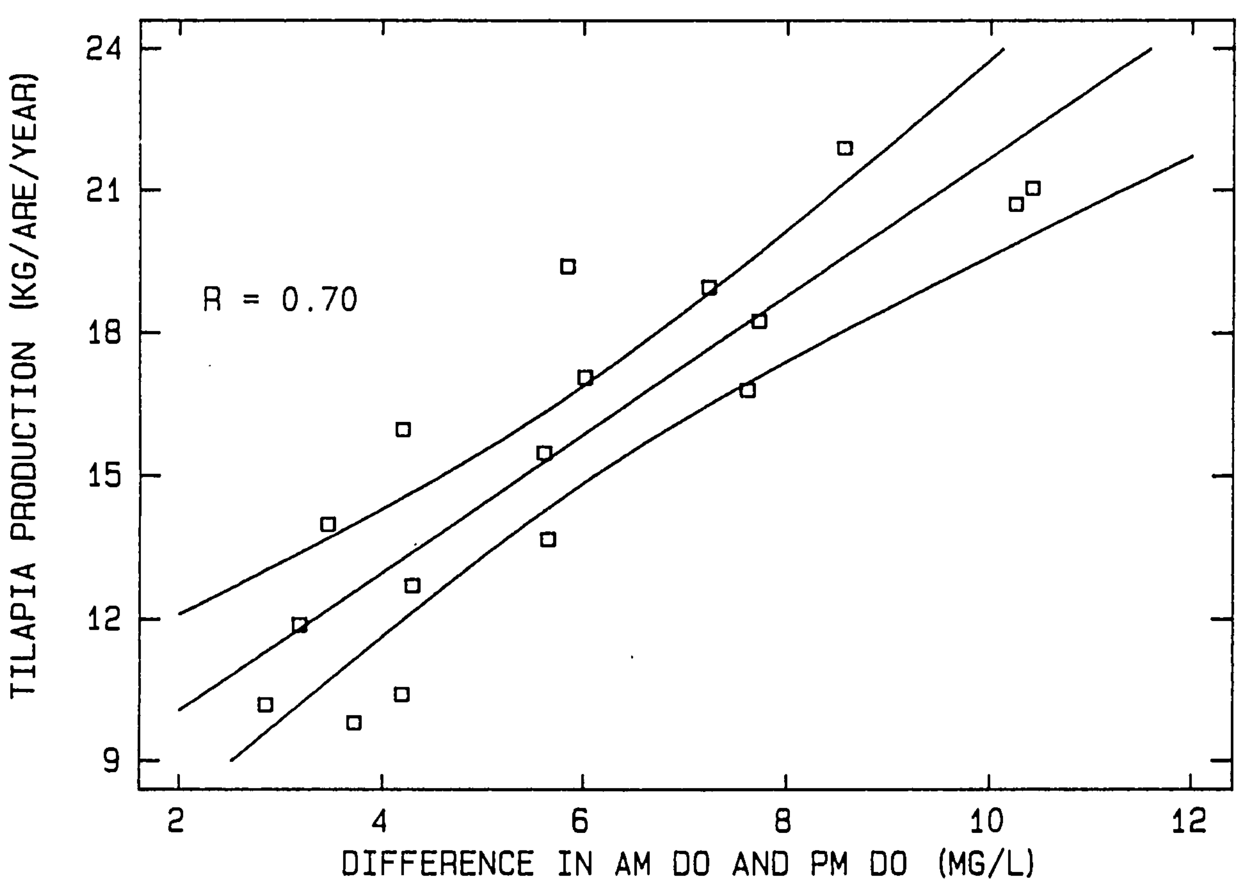

Figure 1. Tilapia (*Oreochromis niloticus*) production versus the difference between morning and afternoon surface dissolved oxygen concentrations.

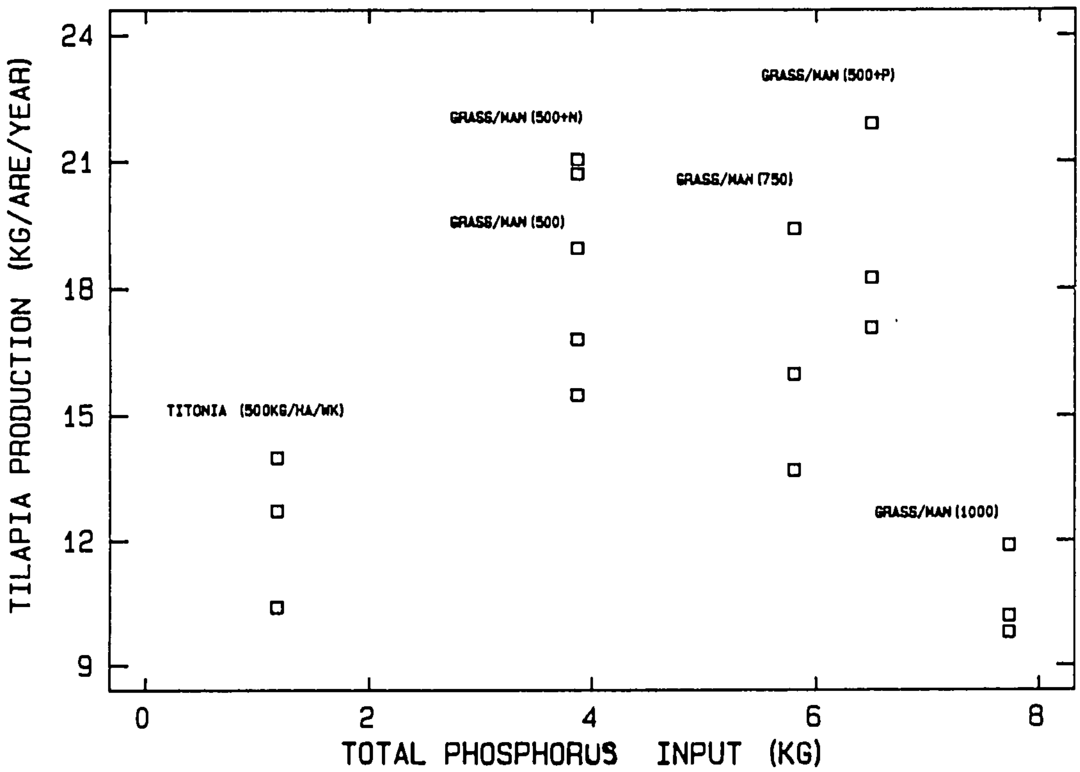

Figure 2. Relationship between tilapia (*Oreochromis niloticus*) production and total phosphorus input for six treatments.

An Economic Analysis of Aquacultural Production Technologies in Rwanda

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Introduction

Fish culture represents a relatively new production alternative for Rwandan fish farmers. The potential of fish culture for supplementing family income and providing high-quality animal protein for home consumption appears to be great.

Fish ponds are being constructed in many parts of the country. Previous studies in Rwanda have indicated that favorable economic returns are possible (Hishamunda et al. 1987; Hishamunda 1988). Yet, little is understood about trade-offs between the benefits and the labor resources required for fish production as compared with those of other, more traditional crops. Economic analysis of the returns to resource utilization in fish farming may shed light on the long-term viability of this new farm enterprise.

Objectives

The primary objectives of this study were to characterize resource availability on Rwandan fish farms, to quantify the resources utilized to produce fish in Rwanda and to estimate net benefits obtained from fish production.

Materials and Methods

Personal interviews were conducted from 29 July 1990 through 12 August 1990 in four communes that had a preponderance of well-established fishponds. Kanama and Mubuga communes were characterized by high-altitude (>1500 m) ponds, whereas Kibayi and Muyira communes had a high percentage of low-altitude (<1500 m) ponds. Fifteen farmers were randomly selected from each commune. The survey instrument elicited information on the labor requirements for various fish production activities, market channels, fish prices, other crops and livestock raised, equipment owned, and types of inputs utilized in fish farming. Corresponding data on pond construction, stocking, fertilization, feeding, and harvesting were recorded from individual pond records maintained by extension agents.

Results

Over 90% of all respondents raised bananas, beans, sweet potatoes, taro, and cabbage, and a majority raised numerous other crops. Over half of all respondents also raised cows, chickens, and goats.

Most of the fish farmers interviewed farmed as part of a group, whereas 40% farmed individually.

Approximately 95% of all fish farmers surveyed sold fish and approximately 69% of all fish produced were sold. Fish farming is clearly a cash crop for Rwandan farmers although pond-raised fish are also used to supplement the diet. Over half of all fish sold were sold on the pond bank.

Of the various production labor activities, cutting grass and leaves for compost and feed occupied most of each fish farmer's time. Harvest labor totalled less than production labor and most of the labor utilized for harvest was spent removing mud and repairing levees.

Cash expenses in fish farming represented only 10% of the total resources used, whereas 90% was used for labor. Net cash returns per 100 m^2 varied from FRW 510 at high altitudes to FRW 1,308 at low altitudes (Table 1). Net returns for the average pond sizes were FRW 1,377 (2.7 ares) in high-altitude ponds and FRW 5,886 (4.5 ares) in low-altitude ponds.

The labor efficiency of food fish production was 0.4 kg of fish produced per person-day of labor. In spite of the fact that low-altitude fishponds produced nearly three times as much fish as high-altitude ponds, more labor was expended to achieve this higher yield and the output of fish per person-day of labor was the same.

Because labor is the main resource used in fish farming, a farmer's decision whether or not to continue raising fish will depend upon the relative benefit of time spent raising fish compared to time spent on other crops. Average yield and market price were used to impute a value for labor utilized in fish farming, FRW 86, Table 2. Survey respondents reported paying FRW 70-80 for hired labor in spite of the official daily wage rate of FRW 100. Therefore, labor utilized in fish farming represents a greater value than the opportunity cost of labor for hire.

Table 1. Cash cost and returns on high- and low-altitude fish farms (100 m^2 ponds), Rwanda Survey, 1989.

		High Altitude			Low Altitude			All Respondents		
ITEM	UNIT	Qty	P/Unit (FRW)	Total (FRW)	Qty	P/Unit (FRW)	Total (FRW)	Qty	P/Unit (FRW)	Total (FRW)
Cash Income[a]										
Food Fish	kg	5.80[b]	150	870	12.68[b]	124	1,572	9.4	136	1,278
Cash Expenses										
Fingerlings	each	67.0	3	201	88.0	3	264	78.0	3	234
Feed/Fert.[c]	total	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total Cash Expenses				360			264			
Net Cash Returns	are	1.0		510	1.0		1,308			1,044
Net Returns/ Av Pond Size	are	2.7		1,377	4.5		5,886	3.6		3,758

[a] Assumes that no fingerlings were sold, although in many cases a certain percent were sold.
[b] The quantity sold is the average harvest weight times the weighted average of percentages of harvest sold for both high and low altitudes.
[c] Nineteen of 26 respondents at high altitudes purchased feed/fertilizer inputs, whereas only 4 of 29 respondents at low altitudes purchased these inputs.

Table 2. Labor efficiency and value of labor utilized in fish farming on high- and low-altitude fish farms, Rwanda Survey, 1989.

Item	Unit	High Altitude	Low Altitude	All Respondents
Food fish harvested	kg	25.3	66.6	47.0
Fingerlings harvested	each	401.0	1,759.0	1,117.0
Labor/crop				
Production	person-day	57.0	129.0	95.0
Harvest	person-day	12.0	25.0	19.0
TOTAL	person-day	69.0	154.0	114.0
Labor efficiency of foodfish production	kg fish/day	0.4	0.4	0.4
Value of labor to produce foodfish	FRW	60.0	60.0	60.0
Labor efficiency of fingerlings produced	fingerlings/day	6.0	11.0	9.0
Value of labor to produce fingerlings	FRW	18.0	33.0	26.0
TOTAL VALUE OF LABOR USED IN FISH PRODUCTION	FRW	78.0	93.0	86.0

References

Hishamunda, N. 1988. Integrated fish farming in Rwanda: yields and economic feasibility. Rapport Annual 1987. Institud des Sciences Agronomiques du Rwanda. Republic of Rwanda.

Hishamunda, N., P. Nyirahabimana, and J. Moehl. 1987. Fish culture in Rwanda: the economic overview. Report, Rwanda Fish Culture Project, Kigembe, Rwanda.

Thailand Technical Reports

The Effects of Stocking Density and Rate of Fertilization on Growth and Reproduction of *Oreochromis niloticus* in Earthen Ponds

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Introduction

Stunted growth is a common occurrence in tilapia grown in crowded ponds. Most workers assume that stunting is simply a result of intense intraspecific competition for limited food resources. Some authors have suggested, on the other hand, that slow growth of pond fish may be due to physiological changes in the way energy is allocated between reproduction and somatic growth. These changes may occur in response to specific environmental cues detected by the fish, cues that are a consequence of the specific management strategy being employed.

Noakes and Balon (1982) suggested that young fish colonizing a newly stocked pond would perceive the environment as being particularly favorable for reproduction, and therefore find it unnecessary to put energy into somatic growth. Lowe-McConnell (1982) considered the aquaculture pond to be a harsh environment, because typical stocking densities far exceed those of natural settings. She further reasoned that fish would begin to breed sooner in a harsh environment, because the prospect for first acquiring more body mass and then reproducing is not good.

This study pursues more information about how stocking densities and fertilization rates affect growth in *Oreochromis niloticus*. In particular, an effort is made to monitor the timing and extent of reproduction in response to different stocking rates and fertilization regimes. The primary goal is to determine whether differences in growth rates can be attributed to differences in reproduction, if they occur.

Materials and Methods

O. niloticus fry of mixed sex and an average weight 2.6 g were stocked at densities of 1 and 3 fish/m^2 in 16 earthen ponds (220 m^2 in surface area), with 8 ponds for each density level. Four ponds from each density level were fertilized with 50 kg chicken manure/ha/wk, and the remaining four ponds from each density level were fertilized with 250 kg chicken manure/ha/wk. Urea (46% N) was added to the ponds along with the chicken manure to make the total input of N five times greater than the total input of P.

Three weeks after stocking, the ponds were seined and fish growth data were recorded from a sample of 10% of the original number of fish stocked in each pond. Five percent of the original stock was removed for gonad analysis, and the remaining 5% was returned to the pond. Subsequent monitoring occurred at 3-week intervals. The sample number and the number removed were adjusted to 10% and 5%, respectively, of the population remaining after the previous sampling and removal. The number of offspring caught with a single passing of the seine was also recorded for each pond at 3-week intervals. Offspring were returned to the pond after each sampling.

Biological and chemical aspects of water quality were monitored biweekly. Physical measurements were made according to the CRSP Fourth Work Plan (January 1989, revision). Stocking occurred on 19 April 1989, and the grow-out period lasted 140 days.

Results

Fish yield data for this experiment appear in Table 1. Yields of adult fish were lower in ponds receiving the low fertilization rate than in ponds receiving the high fertilization rate (average yields were 18.5 and 36.0 kg, respectively). Yields of adult fish and offspring appear to be affected more by the fertilization rate than the stocking density (Figure 1). The yield of offspring was related to the final mean weight of adults (r = 0.75). Survival ranged between 54 and 71 percent.

Table 1. Yield data for ponds stocked with *Oreochromis niloticus* grown for 140 days. Treatment A = low density, low fertilizer; B = low density, high fertilizer; C = high density, low fertilizer; D = high density, high fertilizer.

Pond (trtmnt. no.)	Adult Yield (kg)	Offspring Yield (kg)	Survival (%)	Final Mean Wt. (g)
A1	17.3	3.4	65	79
A2	13.5	6.7	64	69
A3	12.9	2.9	70	61
A4	13.5	4.3	64	65
B1	26.0	17.2	66	131
B2	28.4	20.6	62	160
B3	35.3	26.6	66	156
B4	30.8	12.4	65	163
C1	42.5	6.8	55	80
C2	12.9	4.0	63	21
C3	22.2	1.5	71	39
C4	13.0	2.3	67	19
D1	28.5	8.5	54	60
D2	41.6	17.4	64	68
D3	76.4	5.9	65	129
D4	21.0	5.5	60	40

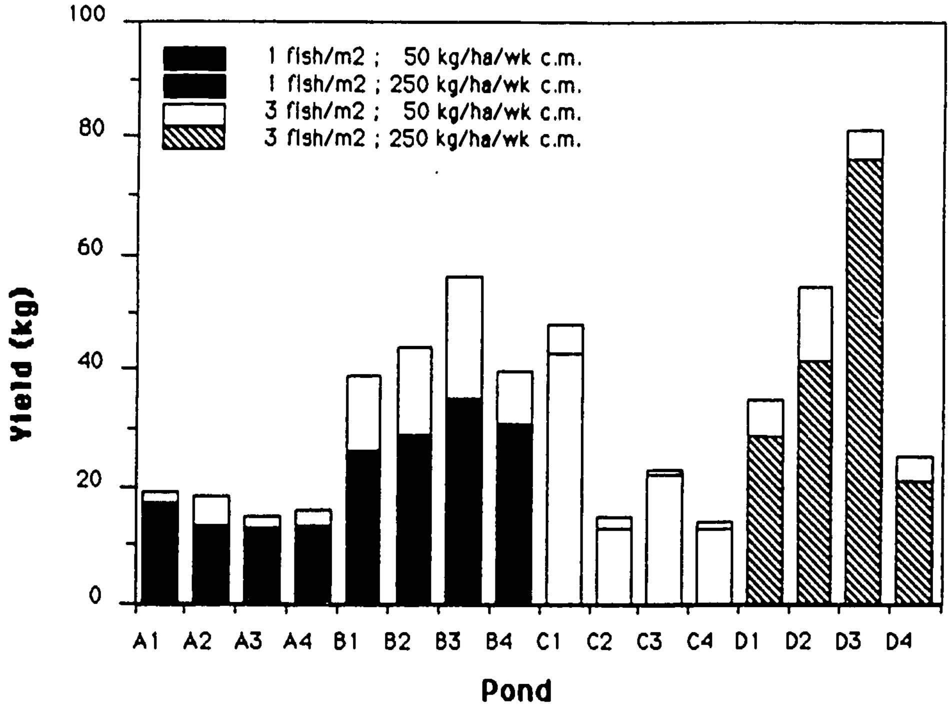

Figure 1. Yield of adult and offspring *O. niloticus* stocked at two densities and grown for 140 days in earthen ponds fertilized with chicken manure supplied at two rates. The top portion of each bar represents offspring yield.

Different rates of growth were achieved by fish stocked under the four experimental treatments. Fish grew the fastest in the low-density, high-fertilizer treatment, and grew the slowest in the high-density, low-fertilizer treatment (Figure 2). Growth in the high-density, high-fertilizer treatment was comparable to that in the low-density, low-fertilizer treatment. In two ponds - one from each of the two high density treatments - growth rates were uncharacteristically high, for reasons unknown at this time.

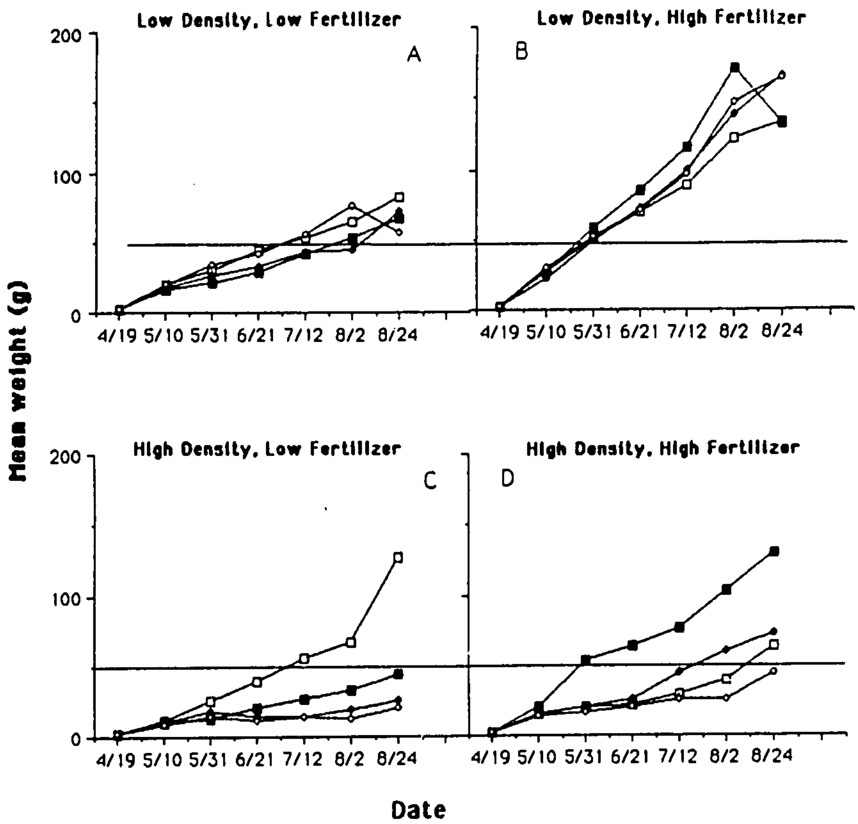

Figure 2. Growth of *O. niloticus* under each management regime. Density levels were 1 and 3 fish/m^2, and fertilization levels were 50 and 250 kg chicken manure (dry weight)/ha/week.

Seasonal averages were calculated for several water quality parameters (Table 2). Net primary productivity was consistently higher in the high-fertilizer treatments than in the low-fertilizer treatments (5151 and 5091 mg C/m^3/d, as compared to 2283 and 2252 mg C/m^3/d), and appears not to have been affected by stocking density. Of the seasonal averages, chlorophyll *a* was the best predictor of adult fish yield (r = 0.84). The good correlation between adult yield and average Secchi disk depth (r = 0.78) corroborates this. Kjeldahl nitrogen and total phosphorus were more closely correlated with final adult fish size than yield (r = 0.79 and 0.84, respectively), but all were related.

Table 2. Water quality data averaged over the grow out period of 140 days. Treatment A = low density, low fertilizer; B = low density, high fertilizer; C = high density, low fertilizer; D = high density, high fertilizer.

Pond (trtmnt. no.)	Net prim. prod. (mg C/m^3/d)	Chlorophyll a (mg/m^3)	Secchi depth (cm)	Ammonia N (mg/L)	Total P (mg/L)	Kjeldahl N (mg/L)
A1		12	29	0.13	0.23	1.92
A2	2283	7	29	0.14	0.13	2.05
A3		0	34	0.09	0.10	1.52
A4		4	29	0.23	0.14	1.88
B1		45	23	0.54	0.18	4.77
B2	5151	80	26	0.39	0.20	3.63
B3		50	18	0.53	0.26	4.34
B4		82	24	0.63	0.28	4.07
C1		66	22	0.06	0.20	2.24
C2	2252	19	30	0.15	0.11	2.00
C3		20	24	0.05	0.13	1.55
C4		21	33	0.12	0.09	1.26
D1		20	25	0.53	0.12	2.74
D2	5091	56	26	0.46	0.17	3.85
D3		119	18	0.09	0.27	3.31
D4		37	32	0.47	0.14	2.93

Anticipated Benefits

At this stage in the analysis of data, little has been revealed about the actual relationship between reproduction and growth. Gonad samples were collected and will be examined further to determine whether differences in the onset and extent of maturation can be detected between treatments, and whether these differences are related to differences in adult growth. Analyses of this sort may lead to new information about patterns of growth and reproduction in tilapia, and may suggest refinements to current pond management strategies.

Literature Cited

Lowe-McConnell, R. H. 1982. Tilapias in fish communities. Pages 83-113 *in* R. S. V. Pullin and R. H. Lowe-McConnell, editors. The biology and culture of tilapias. ICLARM, Manila, Philippines.

Noakes, D. L. G. and E. B. Balon. 1982. Life histories of tilapias: an evolutionary perspective. Pages 61-80 *in* R. S. V. Pullin and R. H. Lowe-McConnell, editors. The biology and culture of tilapias. ICLARM, Manila, Philippines.

Yields of Nile tilapia *(Oreochromis niloticus)* in Fish Ponds in Thailand using Chicken Manure Supplemented with Nitrogen and Phosphorus

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Introduction

Organic fertilizers have had a long tradition of use for increasing fish yields in tropical semi-intensive aquaculture ponds. Several studies have concluded that organic supplements contributed to fish yield by supplying inorganic phosphorus, nitrogen, and carbon for algal growth, and by providing organic carbon for detrital production and heterotrophic utilization (Noriega-Curtis 1979; Olah et al. 1986; Colman and Edwards 1987; Green et al. 1989; Knud-Hansen et al. in press (a)). In waters with low alkalinity, an organic fertilizer such as chicken manure may also be an important source of inorganic carbon for algal uptake through decomposition and the release of carbon dioxide (McNabb et al. 1990). However, organic fertilizers such as chicken manure are phosphorus-rich and nitrogen-poor relative to the 7:1 ratio of N:P required by algae for adequate growth (Redfield et al. 1963; Round 1973; Wetzel 1983). Work that we have done has shown that supplementing chicken manure with urea as a source of nitrogen increased the production of Nile tilapia *(Oreochromis niloticus)* over that which could be obtained using chicken manure alone (Batterson et al. 1990; McNabb et al. 1990). In fact, Batterson et al. (1990) reported yields of over 6000 kg/ha/yr for Nile tilapia, exceeding the value of 5000 kg/ha/yr reported by Balarin (1984) for well-managed farm ponds using fertilizers and feed.

As fish yields increase with greater fertilization rates, it becomes essential to balance the manure and supplemental nutrient inputs to maximize nutrient efficiency while minimizing the development of adverse environmental conditions for the fish. It is known that the application of too much manure may promote increased respiration and deoxygenation of the water column by early morning, which can lead in turn to fish stress and even mortality (Colman and Edwards 1987; Knud-Hansen et al. In press (a)).

The purpose of this study was to increase Nile tilapia production beyond that reported by Batterson et al. (1990), by using chicken manure supplemented with both nitrogen and phosphorus, while minimizing adverse environmental conditions.

Materials and Methods

This research was conducted at the Bang Sai Fisheries Station of the Royal Thai Department of Fisheries, located approximately 60 km northwest of Bangkok, Thailand (14.2°N 100.5°E). Fifteen 0.022-ha earthen ponds were stocked with sex-reversed male *Oreochromis niloticus* at a density of 2 fish/m^2 on 12 October 1989. Fish weight ranged from 8 to 10 g at the time of stocking. Methyltestosterone (Buddle 1984) was used for sex reversal. The fish were harvested after a 147-day growout period on 8 March 1990.

One week prior to stocking and every week thereafter, ponds were fertilized with chicken manure and supplemented with urea and triple superphosphate (TSP). Three ponds were randomly assigned to each of five fertilizer regimes. The five treatments consisted of 25, 75, 125, 175, and 225 kg chicken manure (dry wt)/ha/week, with urea and triple superphosphate added to give all treatments nitrogen and phosphorus inputs of 5.0 and 1.2 kg/ha/day, respectively, for a total N:P ratio of 4:1 by weight. Fresh chicken manure was collected from layers at Kasetsart University, Bangkok, Thailand and analyzed weekly for total Kjeldahl nitrogen (APHA et al. 1985), total phosphorus using perchloric acid digestion (Yoshida et al., 1976), and percent dry weight by drying at 60°C for 12 hours. Results of those analyses were used to calculate urea and TSP inputs. Ponds never overflowed during the experiment and were maintained at an average depth of 0.95 m.

Pond water was collected biweekly between 0800 and 0900 hours as part of the routine water quality monitoring described in Egna et al. (1987). Integrated samples were collected by vertically lowering and capping a pre-rinsed 5-cm (i.d.) PVC tube that was 1.0 m long. Samples were filtered through Whatman GF/C glassfibre filters and analyzed within 24 hours for total ammonia-N (NH_4-N) (indophenol method, Solorzano 1969), nitrate-nitrite-N (NO_3-NO_2-N) (cadmium reduction method, APHA et al. 1985), and soluble reactive phosphorus (SRP) (ascorbic acid method, APHA et al. 1985). Unfiltered water was analyzed for total phosphorus (ascorbic acid method after persulfate digestion, APHA et al. 1985), total Kjeldahl nitrogen, pH and total alkalinity. Total alkalinity was analyzed potentiometrically using 0.02N HCl to titrate the sample to pH 5.1 (APHA et al. 1985). Water temperature and dissolved oxygen were measured in situ with a Yellow Springs dissolved oxygen meter Model 54A. Respiration and net and gross primary productivity were estimated by changes in dissolved oxygen in pond water incubated in situ in light/dark bottles at pond depths of 25, 50, and 75 cm.

Statistical analyses were done according to Steel and Torrie (1980).

Results

The concentrations of nitrogen and phosphorus in the chicken manure used to fertilize the ponds averaged 2.2% (± 0.1) and 2.6% (± 0.1) dry weight, respectively. Based on the N and P concentrations of the chicken manure, urea inputs were 73.8 (±0.2), 71.5 (±0.6), 69.1 (±0.9), 66.7 (±1.2), and 64.4 (±1.5) kg/ha/week, and TSP inputs were 41.4 (±0.8), 34.7 (±2.4), 29.5 (±8.7), 21.5 (±5.6), and 14.9 (±7.2) kg/ha/week, for chicken manure inputs of 25, 75, 125, 175, and 225 kg/ha/week, respectively.

Fish stocking and harvest data are summarized in Table 1. Although all ponds received equal amounts of total N and P, net fish yield (NFY) and mean weights varied considerably between ponds. Extrapolated NFYs for all ponds ranged from 3,374 kg/ha/year to 11,715 kg/ha/year, both values coming from the treatment with the lowest manure input. Adult mean weight ranged from 113 g/fish to 284 g/fish.

Table 1. Fish stocking and harvest data for the experiment.

Chicken Manure Input	Pond No.	Stocking 12-Oct-89		Harvest 8-Mar-90			Total Fry	Net Fish Yield
				Adults				
kg/ha/wk		g/fish	kg/pond	g/fish	kg/pond	% Survival	kg/pond	kg/ha/yr
25	2	8	3.7	113	28.6	56	5.0	3,374
25	3	9	3.5	244	99.2	84	8.1	11,715
25	12	8	3.5	161	75.0	96		8,070
75	4	8	3.8	261	87.4	81		9,435
75	6	10	3.6	232	92.8	89		10,069
75	9	9	3.9	284	98.3	81		10,655
125	8	10	4.0	245	93.0	93	1.4	10,203
125	11	9	3.5	242	85.2	83		9,222
125	16	8	3.6	161	51.0	78	13.3	6,851
175	1	8	3.6	161	55.2	76	0.8	5,915
175	7	8	3.7	191	64.2	81		6,828
175	10	10	3.9	157	69.6	100	0.4	7,461
225	5	8	3.8	229	76.0	74	1.0	8,261
225	13	8	3.6	143	57.7	87		6,106
225	14	9	4.0	137	49.9	76		5,180

Mean NFY decreased from 10,052 (± 610) kg/ha/year to 6,516 (± 1581) kg/ha/year as chicken manure input increased from 75 to 225 kg dry weight/ha/week (Figure 1). The opposite relationship was observed between NFY and TSP input (Figure 2), for which TSP represented from 52.8% to 95.2% of total P loading with decreasing amounts of manure. NFY tended to increase with increasing TSP input except for the highest TSP treatment (the chicken manure loading rate of 25 kg/ha/wk).

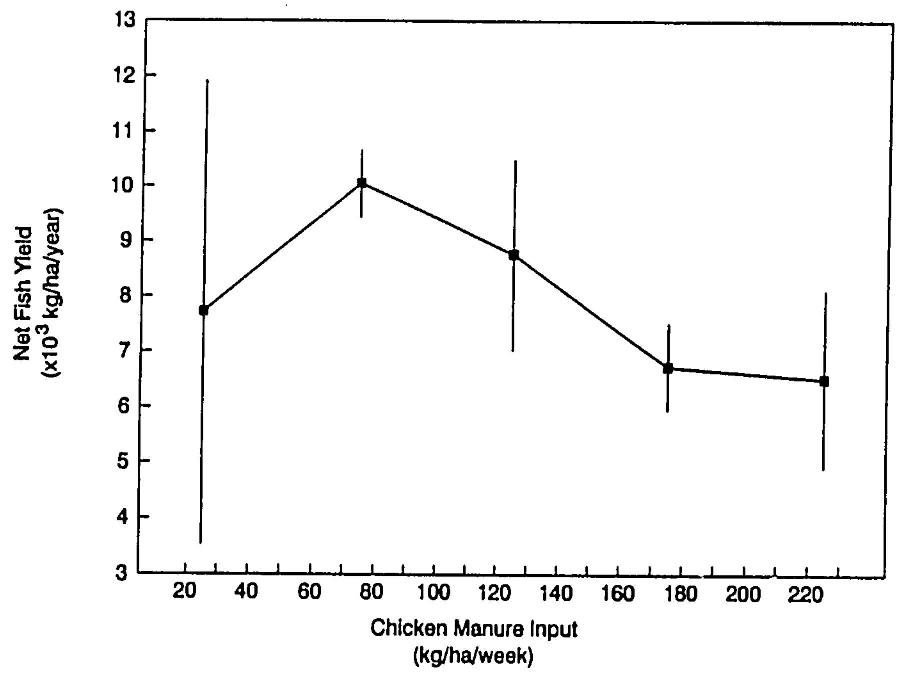

Figure 1. Net fish yields of Nile tilapia (*Oreochromis niloticus*) versus chicken manure input (dry weight) in ponds at the Bang Sai Fisheries Station, Thailand. Data points represent means of three ponds; bars are one standard error. See text for total nutrient inputs.

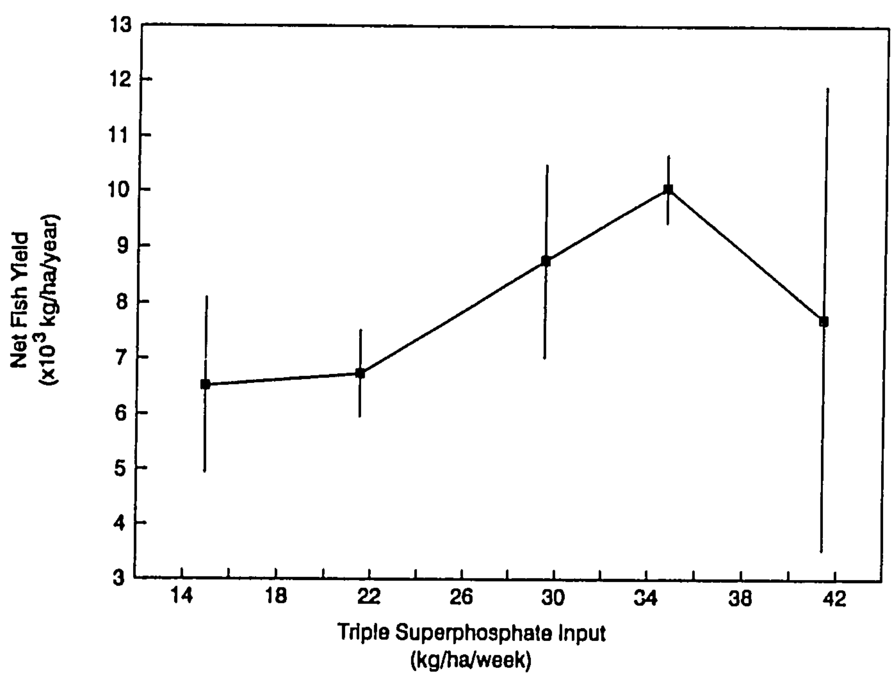

Figure 2. Net fish yields of Nile tilapia (*Oreochromis niloticus*) versus triple superphosphate input in ponds at the Bang Sai Fisheries Station, Thailand. Data points represent means of three ponds; bars are one standard error.

There was a highly significant linear relationship between NFY and primary productivity for 11 of the 15 ponds. The linear relationship between NFY and gross primary productivity (GP) was:

$$NFY = 1279(GP) + 2467, \text{ with } r^2 = 0.73 \text{ and } p < 0.001.$$

There was an even stronger relationship between NFY and net primary productivity (NP). The linear relationship was:

$$NFY = 1775(NP) + 4181, \text{ with } r^2 = 0.87 \text{ and } p < 0.001.$$

These relationships are graphically depicted in Figures 3 and 4, respectively.

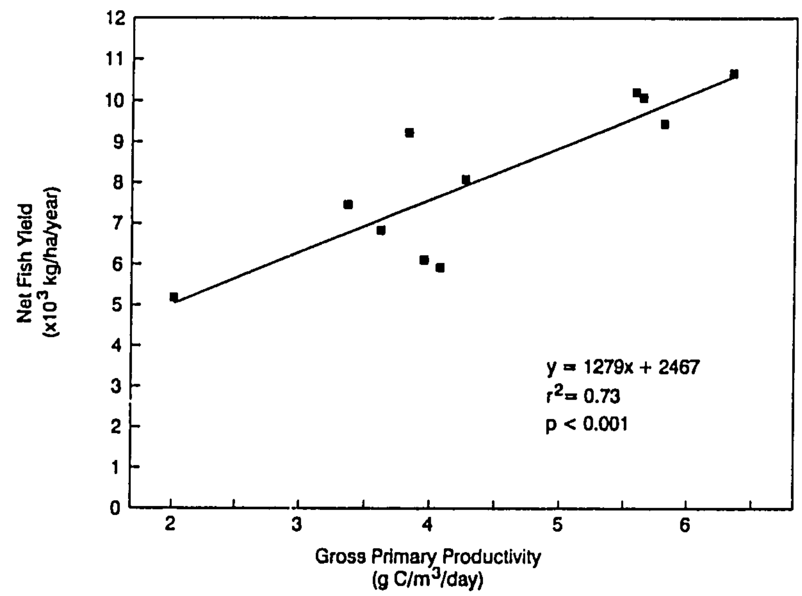

Figure 3. Net fish yields of Nile tilapia (*Oreochromis niloticus*) versus gross primary productivity in ponds at the Bang Sai Fisheries Station, Thailand. Data points represent pond means.

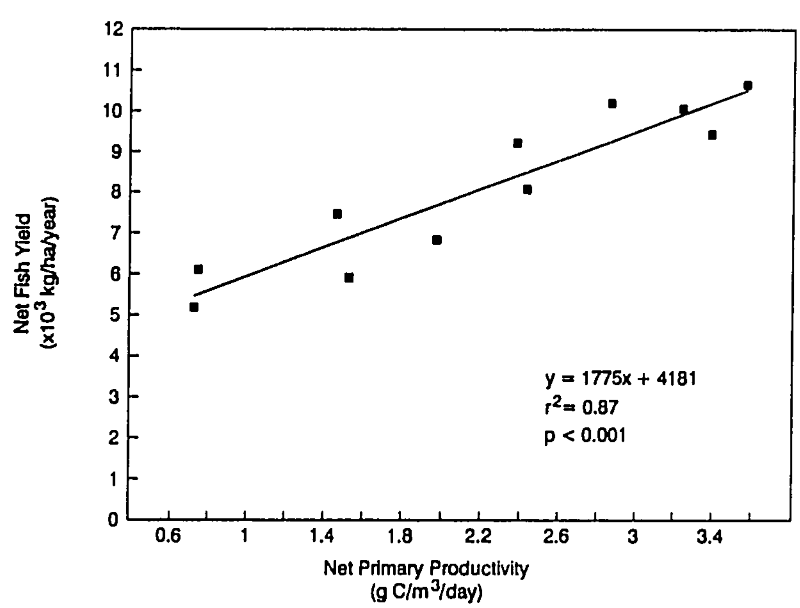

Figure 4. Net fish yields of Nile tilapia (*Oreochromis niloticus*) versus net primary productivity in ponds at the Bang Sai Fisheries Station, Thailand. Data points represent pond means.

Pond respiration rates increased with increasing chicken manure inputs (Figure 5), with treatment means ranging from 8.9 ± 4.7 g O_2/L/day to 16.7 ± 13.5 g O_2/L/day at the highest manure loading rate. The relationship between pond respiration and the amount of manure applied was also reflected in the mean dissolved oxygen concentrations measured at dawn (Figure 5). Dissolved oxygen treatment means ranged from 3.5 ± 0.9 mg/L in ponds that received 25 kg chicken manure/ha/week, to a low of 1.4 ± 0.4 mg/L in ponds that received 225 kg chicken manure/ha/week (the highest loading rate).

Discussion

Mean net fish yields of up to 10,052 (± 610) kg/ha/year were obtained for Nile tilapia by fertilizing with 75 kg chicken manure (dry weight)/ha/week supplemented with 71.5 (± 0.6) kg/ha/week of urea and 34.7 (± 2.4) kg/ha/week) triple superphosphate. This was more than twice the yield that Balarin (1984) reported for well-managed farm ponds using both fertilizer and feeds. These yields were obtained in ponds that averaged about 2.5 mg/L of dissolved oxygen in the early morning (Figure 5). These dissolved oxygen levels did not lead to fish stress or excess mortality.

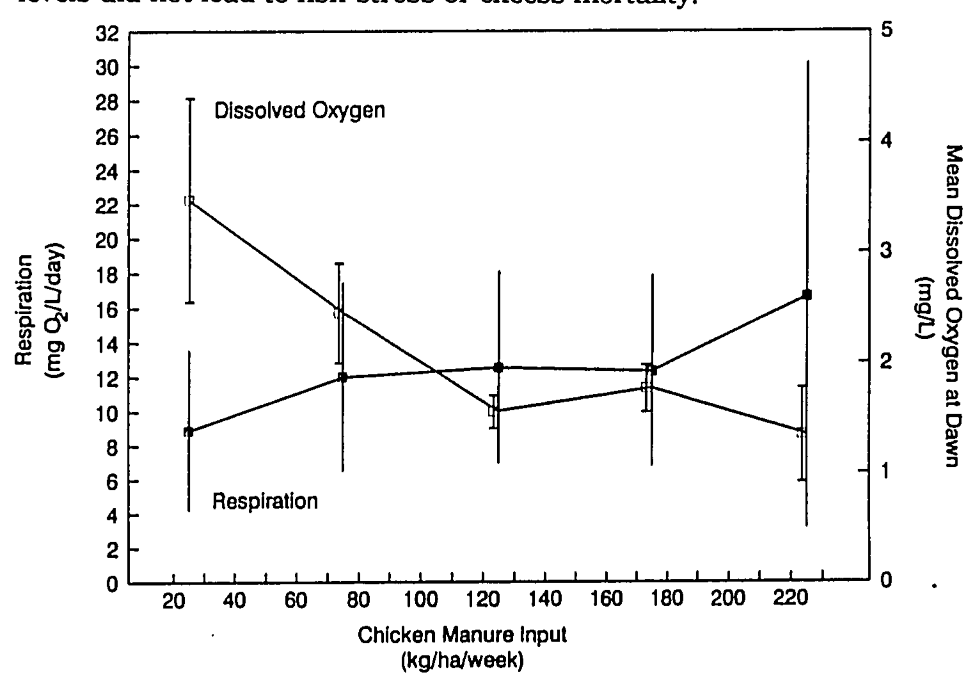

Figure 5. Whole pond respiration and mean dissolved oxygen at dawn versus chicken manure inputs (dry weight) in ponds at the Bang Sai Fisheries Station, Thailand. Data points represent pond means; bars are one standard error.

NFY was significantly linearly correlated to primary productivity (Figures 3 and 4), which is similar to results reported by McConnell et al. (1977) and Knud-Hansen et al. (In press (b)). The fact that the y intercepts of the linear relationships between NFY and both GP and NP were significantly greater than zero indicates that something other than algal production was partly responsible for fish production. Figure 1, however, clearly demonstrates that if chicken manure-derived detritus did contribute to the diet of

Oreochromis niloticus, as suggested by others (Noriega-Curtis 1979; Olah et al. 1986; Colman and Edwards 1987; Green et al. 1989; Knud-Hansen et al. in press (b)), then this need can be satisfied with no more than 75 kg chicken manure/ha/week. Furthermore, these data would support the conclusions of Schroeder and Buck (1987), who reported that manure-derived detritus had only a minor influence on tilapia production.

Anticipated Benefits

The work that is reported here indicates that high yields of Nile tilapia can be obtained with nominal chicken manure loading (75 kg/ha/week) if it is supplemented with nitrogen and phosphorus sources. The supplemental nitrogen and phosphorus sources, urea and TSP, are expensive relative to chicken manure, based on current Thai market prices. However, the cost per gram of available N and P in urea and TSP is significantly less than that of chicken manure. Therefore, using chicken manure supplemented with urea and TSP results in the same total loading of N and P as chicken manure at a lower cost to the farmer.

References

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1985. Standard methods for examination of water and wastewater. 16th edition. American Public Health Association, Washington, D.C. 1268pp.

Balarin, J.D. 1984. Intensive tilapia culture: a scope for the future production in developing countries. Outlook in Agriculture 13:10-19.

Batterson, T.R., C.D. McNabb, C.F. Knud-Hansen, and K. Jaiyen. 1990. Yields of tilapia with nitrogen-supplemented organic fertilizers in fish ponds in Thailand. Pages 30-33 *in* H.S. Egna, J. Bowman, and M. McNamara, editors. Title XII Collaborative Research Support Program Pond Dynamics/Aquaculture Seventh Annual Administrative Report 1989. PD/A CRSP, Oregon State University, Corvallis, Oregon.

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

Colman, J., and P. Edwards. 1987. Feeding pathways and environmental constraints in waste-fed aquaculture: balance and optimization. Pages 240-281 *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.

Egna, H.S., N. Brown, and M. Leslie. 1987. Pond Dynamics/Aquaculture Collaborative Research Data Reports. Volume One: General Reference. Site Descriptions, Materials and Methods for the Global Experiment. Pond Dynamics/Aquaculture Collaborative Research Support Program, Office of International Research and Development, Oregon State University, Corvallis, 84 pp.

Green, B.W., R.P.Phelps, and H.R. Alvarenga. 1989. The effect of manures and chemical fertilizers on the production of *Oreochromis niloticus* in earthen ponds. Aquaculture 76:37-42.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson. In press (a). Application of limnology for efficient nutrient utilization in tropical pond aquaculture. Verhandlungen Internationale Vereinigung Limnologie.

Knud-Hansen, C.F., C.D. McNabb, T.R. Batterson, I.S. Harahat, K. Sumatadinata, and H.M. Eidman. In press (b). Relationship between nitrogen input, primary productivity and fish yield in Indonesian aquaculture ponds. Aquaculture.

McConnell, W.J., S. Lewis, and J.E. Olson. 1977. Gross photosynthesis as an estimator of potential fish production. Transaction of the American Fisheries Society 106(5):417-423.

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K..Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. Pages 169-172 *in* R. Hirano and I. Hanyu, editors. Proceedings of the Second Asian Fisheries Forum, 17-22 April 1989, Tokyo, Japan.

Noriega-Curtis, P. 1979. Primary productivity and related fish yield in intensely manured fishponds. Aquaculture 17:335-344.

Olah, J., V.R.P. Sinha, S. Ayyappan, C.S. Purushothaman, and S. Radheyshyam. 1986. Primary production and fish yields in fish ponds under different management practices. Aquaculture 58.

Redfield, A.C., B.H. Ketchum and F.A. Richards. 1963. The influence of organisms on the composition of sea water. Pages 27-28 *in* M.A. Hill, editor. The sea. Volume 2. Interscience Publishers, New York.

Round, F.E. 1973. The biology of the algae. 2nd edition. St. Martin's Press, New York. 278pp.

Schroeder, G.L. and H. Buck. 1987. Estimates of the relative contributions of organic and mineral contents of manure to fish growth. Journal of Aquaculture in the Tropics 2:133-138.

Solorzano, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnology and Oceanography 14:799-801.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd edition. McGraw Hill, New York, 633 pp.

Wetzel, R.G. 1983. Limnology. 2nd edition. Saunders College Publishing, New York. 858pp.

Yoshida, S., D.A. Forno, I.H. Cook and K.A. Gomez. 1976. Laboratory manual for physiological studies of rice. 3rd edition. IRRI, Manila, Philippines.

Production of *Oreochromis niloticus* and Ecosystem Dynamics in Manured Ponds of Three Depths

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Abstract

During two five-month experiments in Thailand, unfed ponds of approximately 370 m^2 surface area were stocked with male nile tilapia (*Oreochromis niloticus*) fingerlings of 4 to 12 g weight at densities of 0.5 to 1.6 fish/m^2 in triplicated treatments in ponds of 0.6, 1.0, and 1.5 m depth. Stocking and fertilization (with chicken manure, urea, and TSP) were proportional to pond volume in some treatments and to pond area in others.

Survival rates of 66 to 98% and final fish weights of 96 to 313 g were never related to depth or to stocking density. Yields of 0.9 to 6.3 t/ha/yr varied with depth during the higher-yielding, dry-season experiment, but were proportional to stocking and fertilization.

Dissolved N and P and suspended solids showed little relation to depth treatments (Figure 1); chlorophyll concentrations were higher in treatments receiving greater fertilizer inputs per unit volume. Chlorophyll *a* and organic suspended solids were related in a manner indicating that phytoplankton accounted for most suspended organic matter. Production of dissolved oxygen was inversely related to depth in the dry-season experiment, even with volume-proportional fertilization (Figure 2). This finding is consistent with model predictions of optimal photosynthesis at shallower depths.

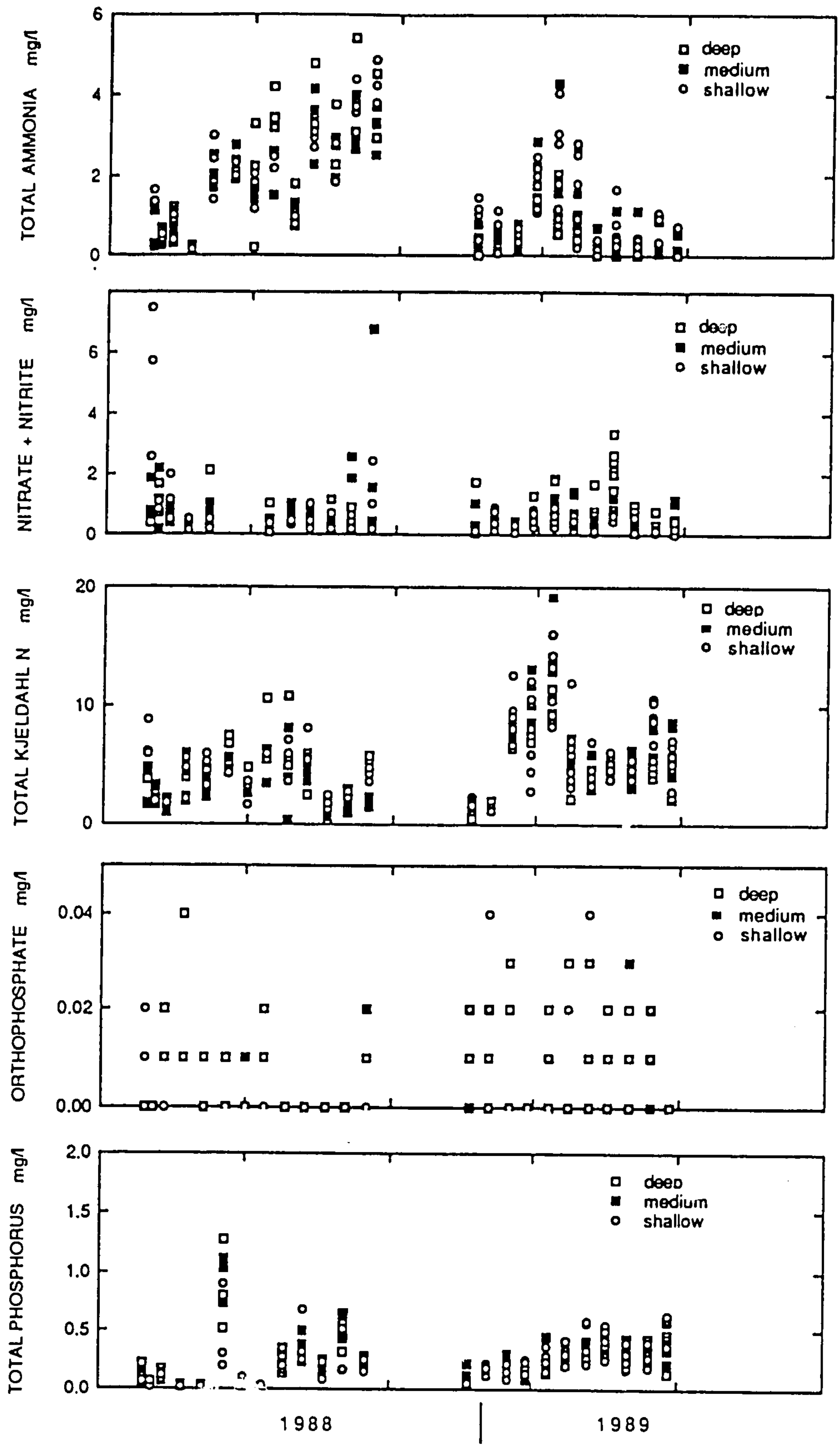

Figure 1. Concentrations of dissolved forms of N and P during biweekly samplings in Experiment 1 (1988) and Experiment 2 (1989). Some points are obscured by overlap on most dates.

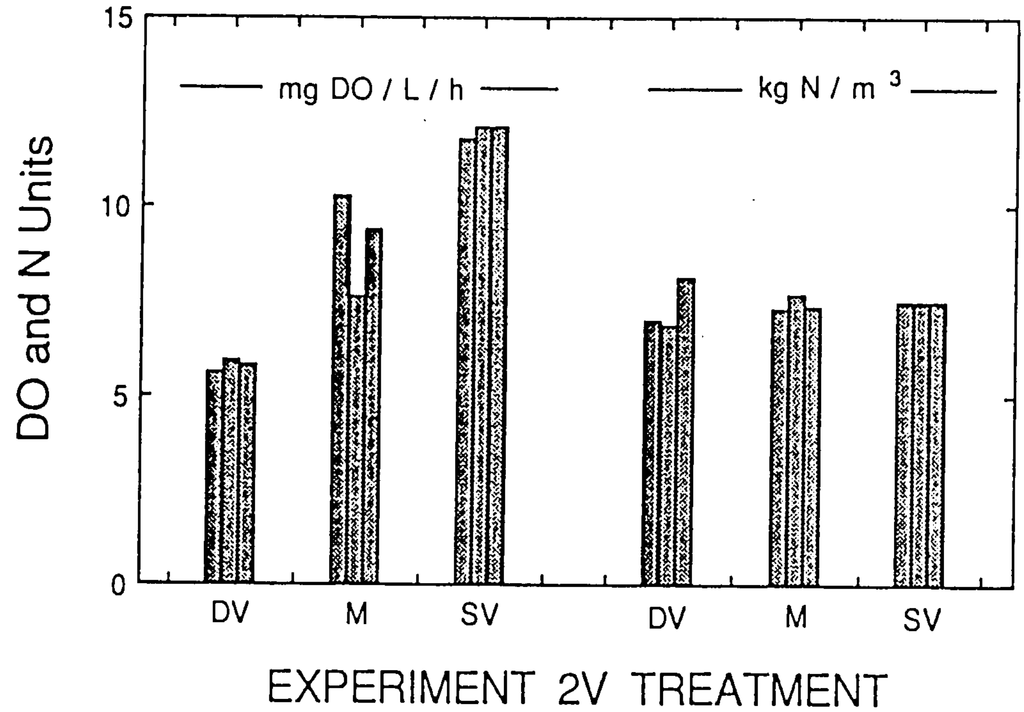

Figure 2. Mean weekly gross production of dissolved oxygen (DO) and total volume-specific nitrogen inputs in fertilizers for volume-proportional treatments during Experiment 2 (V).

Techniques for Assessment of Stratification and Effects of Mechanical Mixing in Tropical Fish Ponds*

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Abstract

Density stratification isolates near-surface from bottom pond waters and prevents exchange of dissolved oxygen (DO) and nutrient elements, potentially restricting photosynthesis and production. Destratification strategies have become important for cost-effective intensification of pond aquaculture. Evaluation of methods and devices has emphasized effects on production, with little detailed description of effects on physicochemical components of pond ecosystems.

This paper describes short-term effects of mechanical mixing on temporal and spatial distribution of temperature and DO in tropical freshwater fish ponds. Intensely stratified ponds of 1.5 m depth were monitored at eight

depths for temperature and two depths for DO every 30 min with a low-cost automated system of commercially available hardware. Results are presented as time-series plots, isotherm diagrams of temperature distribution with time and depth, and a stability index of energy required to mix a pond to uniform temperature.

Required mixing energy is minuscule compared with electrical energy consumption of the lowest-powered mixing devices discussed in literature. Strategy for application of mechanical energy to water is critical for efficiency. A relatively subtle difference between two mixing regimes (daytime mixing for one 2-h period or two 1-h periods) produced potentially important differences in temperature and DO distribution.

**This paper has been accepted for publication in Aquacultural Engineering.*

Oreochromis niloticus Growout Under Conditions of High Nitrogen and Phosphorus Input

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Abstract

Triplicate 0.222-hectare ponds at the Ayutthaya (Thailand) CRSP site were fertilized with 25, 75, 125, 175, and 225 kg chicken manure/ha/wk (dry weight), and supplemented with urea and triple superphosphate (TSP) so that all 15 ponds received an average of 0.5 g N/m^2/day and 0.12 g P/m^2/day. Ponds were stocked with with 10- and 20-g sex-reversed male *Oreochromis niloticus* at a density of 2 fish/m^2. Extrapolated data (experiment ends 8 March 1991) suggest that a minimum net fish yield (NFY) of over 12,000 kg/ha/yr will be obtained with a manure input of 75 kg/ha/wk, with mean NFYs decreasing to about 8,000 kg/ha/yr at the highest manure loading rates. Within-treatment NFY variability was examined. It appeared to be related to nutrient utilization efficiency, with higher yields found in ponds where primary productivity was relatively high and afternoon ammonia-N concentrations were generally below 0.3 mg/L. NFY was relatively low within treatments in ponds where total alkalinity dropped below 30 mg $CaCO_3$/L and ammonia concentrations were >1.0 mg/L. Reduced primary productivity was observed in these ponds. It may have been due to inorganic carbon limitation with the result that algal uptake was low and ammonia reached high concentrations. Reasons are unclear as to why alkalinity steadily diminished in some ponds during the five-month experiment.

Reporting Fish Growth: A Review of the Basics

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Abstract

Aquaculturists typically report growth using absolute (g/d), relative (% increase in body weight), and specific growth rates (%/d). Less frequently, Von Bertalanffy Growth Functions (VBGF) are used. Each of these rates is a numerical representation of growth which assumes a specific relationship between size and time (linear, exponential, or asymptotic). Aquaculturists typically collect size-at-time data throughout their experiments. Unfortunately, the intermediate data points are usually ignored when computing growth rates (except for VBGF) and the appropriateness of the growth rate for a particular data set is not tested. This paper reviews the basis for and computation of each of the growth rates in an effort to encourage aquaculturists to only use growth rates which correspond to their data.

V. United States Research Component of the Global Experiment

Introduction

Implicit throughout Title XII of the International Development and Food Assistance Act of 1975 is that activities should be mutually beneficial to developing countries and the United States. In planning this CRSP, consensus among CRSP participants was that improving the efficiency of pond culture systems through collaborative research involving both U.S. and developing country institutions would be mutually beneficial. However, subsequent to awarding the CRSP grant, USAID interpreted "mutually beneficial" to mean that the CRSP should fund research activities both in the U.S. and in developing countries and instructed the CRSP to direct some of its funds to support research activities at the U.S. institutions.

The U.S. Research Component was organized during the third year of the CRSP. A number of Special Topics Research Studies have been funded and successfully completed since that time. These projects have studied timely research problems that could not be addressed in the overseas component. Consequently, the projects help to strengthen the overall effectiveness of the CRSP.

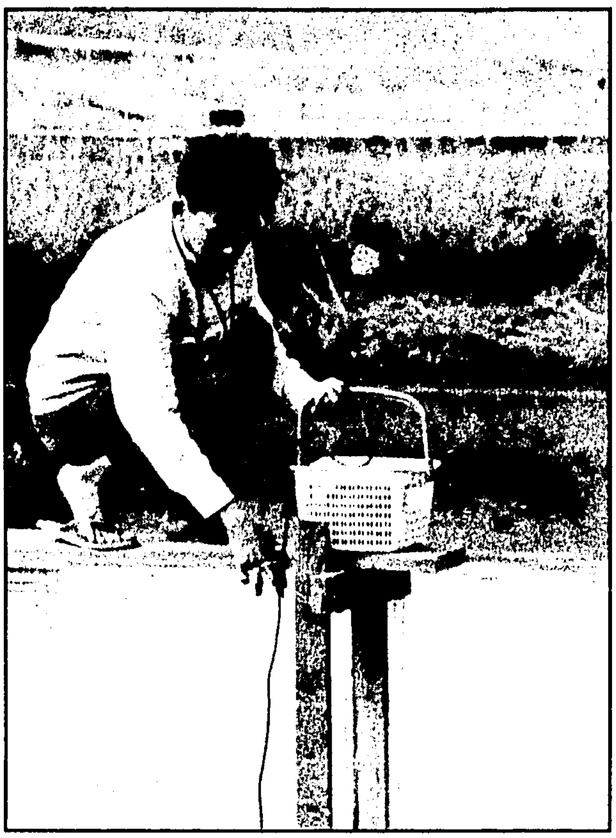
In planning the U.S. Research Component, the CRSP endeavors to ensure that the projects included in this activity are of high technical merit. Formal project proposals are subjected to critical review by peers not affiliated with institutions participating in the CRSP. The proposals and reviews are then submitted to the CRSP Board of Directors for approval. The Board considers the relevance of the proposed work to CRSP goals as well as its technical merit.

The Special Topics Research Studies described above are only one part of the U.S. Research Component. The overall success of the CRSP depends heavily on the management, analysis, and modeling of data collected from the overseas CRSP sites. Comprehensive analysis of the global data is accomplished at several U.S. universities as part of the Data Analysis and Synthesis Team's activities. Although the CRSP Central Data Base is not part of the U.S. Research Component, it is described in this section because its output provides the foundation for activities conducted by the Data Analysis and Synthesis Team.

The Data Analysis and Synthesis Team and The Central Data Base: Background

The CRSP recognized at the outset that aquaculture ponds are extremely complex ecosystems. The choice of sites, the experimental protocols, the monitoring of variables, and the frequency of measurements were all determined with an understanding of the complexity of the system. Results obtained to date have confirmed this initial perception and have made the establishment and maintenance of a complete data base and the computerized analysis of the data a necessity.

The CRSP Central Data Base is maintained by the Program Management Office. Field personnel send data to their principal investigators at the U.S. universities who check the data sets and forward them to the Program Management Office. The data sets then are electronically translated into a standardized format and sent back to the principal investigators for verification. (Data entry already are standardized through the use of templates that were developed by the Data Base Manager and approved by the Technical Committee.) Verified files are entered in the Central Data Base for use by the Data Analysis and Synthesis Team. Specific data sets may be retrieved in virtually any format desired. All project teams also independently analyze their data and most have had their results published in journals or proceedings of scientific meetings (see Appendix A).



The CRSP, through its data base, provides a great service for the world aquaculture community by collecting daily measurements of photosynthetically active radiation, rainfall, evaporation, air temperature, and wind speed concurrently with experimental data from ponds. Detailed records such as these are rare in the aquaculture literature. This is particularly true for photosynthetically active radiation and on-site rainfall, which are important features of water and nutrient budgets for ponds in the wet tropics. Other records collected by the CRSP also are useful in interpreting pond measurements in relation to physical processes occurring at the surface.

A major accomplishment of previous reporting periods was the completion of the Central Data Base. Complete and verified data sets from all sites for the first three experimental cycles have been available to members of the Data Analysis and Synthesis Team and to other participants since that time. Additional data, generated under the activities of the Fourth and Fifth Work Plans, have been added to the Central Data Base during this reporting period.

The Data Analysis and Synthesis Team (DAST) was established in September 1985 to provide comprehensive, global interpretations of the CRSP Central Data Base. The Data Analysis and Synthesis Team's activities are decentralized; members of the Team operate from offices at the University of

California at Davis, the University of Michigan, and Oregon State University. Through their involvement on the Technical Committee, members of the Data Analysis and Synthesis Team interact with scientists from the field-based research component of the Global Experiment. The Data Analysis and Synthesis Team works in concert with the Data Base Manager to translate and verify the large amount of data that have been compiled into the CRSP Central Data Base.

The primary objectives of the Data Analysis and Synthesis Team include:
- development of data management techniques;
- definition of site-specific as well as global relationships; and
- development of computer models that make optimum use of the CRSP Central Data Base and are suitable for diverse applications such as teaching, management, planning, and research.

In previous years the Data Analysis and Synthesis Team performed basic statistical analyses on the data. A few significant relationships were revealed. Whereas these relationships were determined from the partial data base and did not necessarily provide a general relationship for all research sites, they did show the existence of possible statistical relationships in the data. Additional interpretations of the data presently are being conducted with other statistical methods such as principal component analysis and multiple regression.

The CRSP aims to increase the usefulness of aquaculture models by addressing the limitations inherent in previous computer models, such as difficulty of use, non-compatibility between computers, and oversimplifications of system dynamics. Developers of previous models did not have the benefit of a large standardized data base such as the one created by the CRSP. The Data Analysis and Synthesis Team is using this data base to develop several improved computer models. These include models to analyze fish growth and factors limiting growth and production, as well as mechanistic models for simulating and predicting pond water quality conditions such as dissolved oxygen concentrations and cycles. In some cases the work involves modifying previously available *fisheries* models for use in *aquaculture*, while in others new models have been constructed for calibration and verification using CRSP data. Much of the work is based on a generalized descriptive model of pond ecosystems developed by CRSP participants during earlier phases of the project (Figure 1).

One of the ultimate objectives of the CRSP is to compile a manual of pond management guidelines for the end-users in aquaculture—the fish farmers and pond managers. Toward this end a computer expert system has been developed to provide pond management guidance based on knowledge gained through CRSP research and modeling as well as on information from independent sources. The expert system can be used directly by those with access to personal computers; perhaps more importantly, it will provide the basis for printed management guidelines. This system, and the printed guidelines which it generates, will address management questions such as the appropriate amendments to be added to ponds, the amounts and frequencies of application, and the least-cost combinations of available amendments which will meet the needs of given ponds.

Benefits of analyzing results and developing computer models that simulate pond conditions at the experimental sites will occur on several levels; management and production, design, and planning. The quantification of relationships between variables and the effect of treatments will allow farmers to adopt management practices to achieve production goals within local constraints of climate, water, feed, and fertilizer availability. Design of production systems will be improved by matching production facilities and costs with production goals. As the Data Analysis and Synthesis Team moves closer to meeting its objectives, the CRSP will begin to realize its goal of confronting food and nutritional problems through improved aquaculture technologies that can be made available to fish farmers both in the US and abroad. The efforts of the DAST members toward this goal during the past year are detailed in the reports that follow.

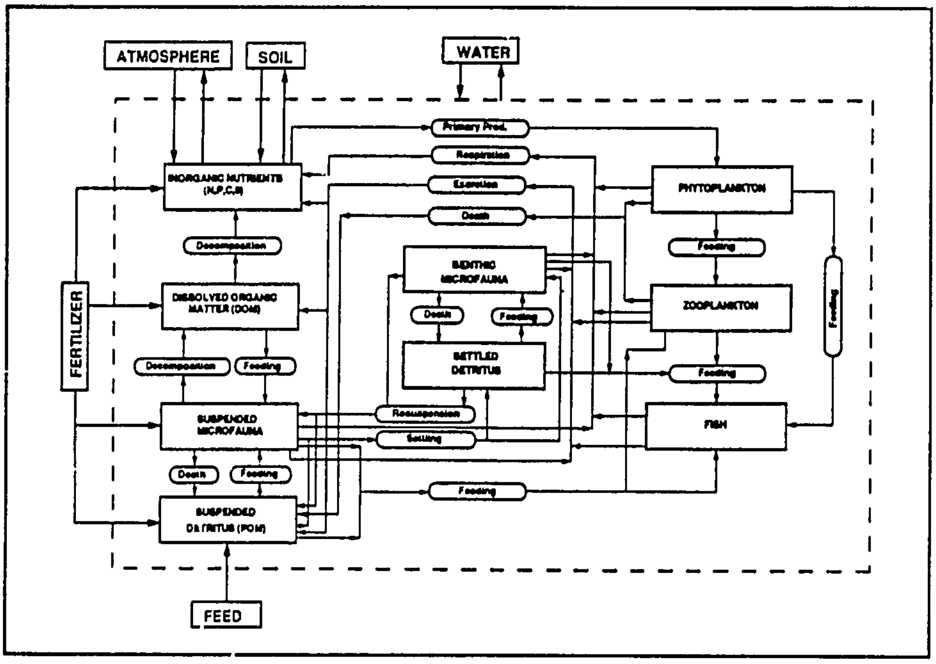


Figure 1. A CRSP conceptual model of an aquaculture pond. The arrows connecting the model's components represent the paths for movement of mass in the system. The system includes both biological and non-biological components. The strictly biological components are phytoplankton, zooplankton, and fish, whereas the non-biological components are the inorganic nutrients that are considered likely to limit productivity. Examples of limiting nutrients for photosynthesis are nitrogen, carbon, phosphorus, oxygen, and nitrogen (ammonia), which affect fish growth, health, and survival. Sediments include decomposing organic matter that settles from the water, the parent soil material, and benthic organisms. Particulate organic matter is a composite of dead particulate organics and bacteria that either coat the particles or are in free suspension. Most research on fertilized aquaculture ponds has been based on the premise that yields and production rates are determined by primary productivity. Nutrients added to a pond must undergo transformations that include fixation by phytoplankton before they are available to fish. The importance of the heterotrophic food chain has not been recognized until recently.

Summary of Activities: Data Analysis and Synthesis Team

The work of the Data Analysis and Synthesis Team (DAST) continued according to the Fifth Work Plan. The main areas of activity identified in the Work Plan, and the DAST member given primary responsibility for each area were as follows:

1. Statistical analysis of the data, concentrating on fish growth (Chang).
2. Analysis and modeling of pond dynamics (Piedrahita).
3. Pond classification techniques and pond management guidelines (Lannan).

A major achievement of the DAST during this period has been the development of a set of preliminary pond management guidelines. Field testing and validation of the guidelines will be necessary prior to their use in extension and planning activities. During this period, the DAST also identified specific areas where field research would be particularly productive in enhancing our understanding and ability to manage production ponds. A list of these areas was developed from a synthesis of the DAST's analyses of 1) the CRSP Central Data Base, 2) the computer models, and 3) the management guidelines. The list was circulated to CRSP researchers to guide the planning of field experiments for the next Work Plan. Further progress by the DAST in summarizing CRSP findings depends, to a large extent, on the successful incorporation of these research topics and priorities into the field experiments to be carried out during the next research cycles.

Analysis and Modeling of Water Quality in Ponds

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Introduction

The focus of the UC Davis component of the DAST during the 1989-90 year has been on the analysis of primary productivity, including phytoplankton photosynthesis and respiration rates. Additional work, on the analysis of fish growth time histories, was undertaken to develop predictive relationships that can be incorporated into pond management guidelines.

The information derived from the various models has been used to identify areas requiring further research and to develop hypotheses for field testing. These suggestions and hypotheses have been presented in a quarterly newsletter initiated in March 1990. The newsletter is distributed to CRSP participants.

Previous Work

Previous work at UC Davis resulted in the development of mechanistic and empirical models of pond processes. The models included:

- a mechanistic ecosystem model to simulate 14 state variables (The Aquaculture Pond model, TAP; formerly called PondEco);
- a mechanistic model to simulate dissolved oxygen concentration (PondDO);
- a mechanistic model to analyze diurnal measurements of dissolved oxygen, pH, temperature and alkalinity (WholePond);
- an empirical model to predict fish growth as a function of time-after- stocking, fish weight at time of stocking, and two parameters derived empirically.

These models have been described in previous CRSP reports and in other publications. The TAP and WholePond models had been run with data from the first three experimental cycles.

Objectives

Activities at UC Davis during the 1989-90 year relate to two of the DAST goals and objectives stated in the Fifth Work Plan:

1. To determine the numerical relationships between variables and the critical rate processes required for predicting responses of pond production systems, and

2. To develop computer models that can be used to examine paradigms of pond dynamics, to propose management actions for field testing, and to identify topics deserving further research.

The DAST studies related to these goals, and the objectives addressed are:

DAST Study 1: Data Analysis

? To estimate the numerical relationships between fish growth, environmental conditions, and nutrient inputs.

DAST Study 2: Ecosystem Model

1. To identify general topics requiring further field research
2. To develop specific hypotheses for possible field testing
3. To develop pond management guidelines based on model results.

DAST Study 3: Dissolved Oxygen Models

1. To develop techniques for field evaluation of phytoplankton "condition"
2. To develop techniques for oxygen management.

Results

Some of the results obtained from the DAST studies were presented at the CRSP annual meeting in May 1990, and have also been summarized in the DAST newsletters. General descriptions of the findings and progress of the DAST studies are presented below.

DAST Study 1

The analysis of fish growth was undertaken to determine growth rates and possible relationships between growth rates and environmental variables. The procedure and equations used to predict fish weight at any time in the growth cycle were described in the Seventh Annual Administrative Report and are summarized here for clarity. Total fish biomass values in each pond were obtained from the F-templates of the CRSP Central Data Base. The values for replicate ponds (i.e., ponds receiving the same treatment) were averaged. The time history for each treatment was then analyzed by non-linear regression to fit an exponential growth model tending towards an asymptote (Figure 1):

$$FWeight = FWeight_0 \bullet Exp\ (-Time \bullet B) + A \bullet (1 - Exp\ (-Time \bullet B) \quad (1)$$

where:

FWeight	=	Average weight of a fish (g)
$FWeight_0$	=	Average fish weight at time of stocking (g)
A, B	=	Fitted parameters for the exponential growth model
Time	=	Time from the time of initial stocking (d)

The model was run for all the possible data sets for the first three experimental cycles. Data from the five freshwater sites (Ayutthaya, Bogor, Butare, Comayagua, and Gualaca) were run, but not all of the results were included in the final data analysis due to incomplete information, particularly with respect to the type of treatment being applied to each of the ponds. The proposed model fits the data very closely, resulting in very high Pseudo-R^2 values, with over 80% of the runs having Pseudo-R^2 values of at least 0.96.

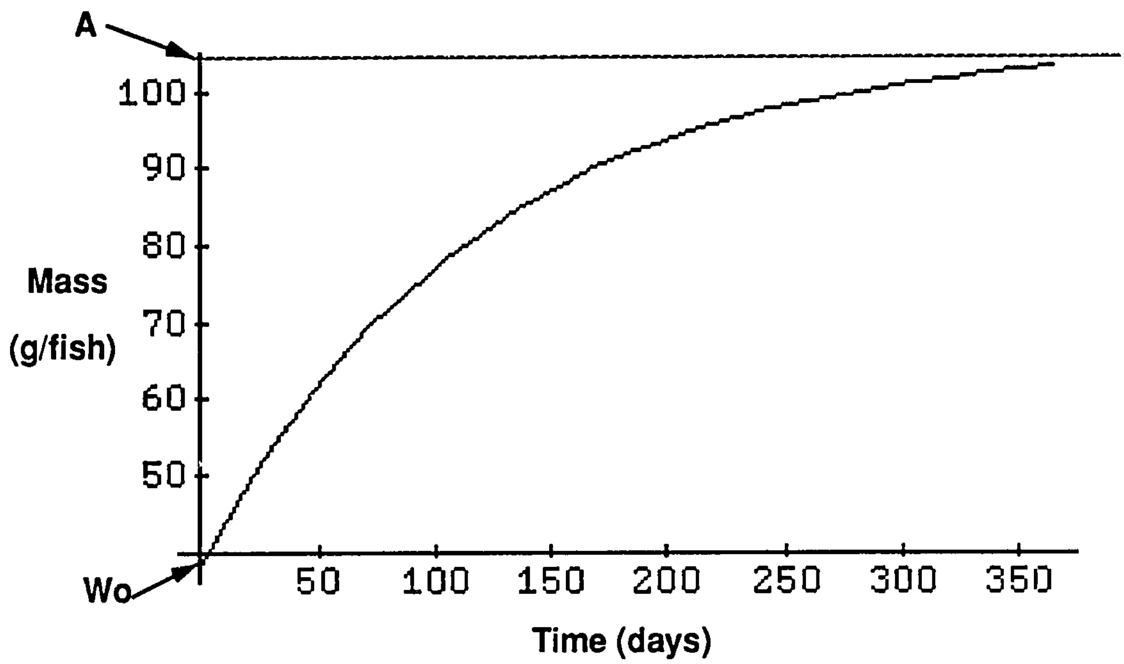

Figure 1. Fish growth curve showing the asymptote (A) and initial weight (W_o).

Statistical analysis of the asymptote (A) and growth coefficient (B) values was undertaken to develop predictive relationships that could be used to estimate the values of A and B based on pond fertilization regime, climate, or other water quality parameters. Despite the success of the predictive growth model, results of statistical analysis were inconclusive in large part due to the incomplete nature of the data set. Data for all the treatments were not available for all sites or all seasons. Based on the limited data available for analysis, however, there were significant differences (95%) found in the asymptote and growth coefficient as a function of season and location. There was no significant difference in the asymptote for the different fertilization regimes used, and only one treatment (triple superphosphate fertilization) showed a significantly different growth coefficient.

The growth rate can be obtained by differentiating Equation 1 with respect to time:

$$GR = (B \bullet (A - FWeight_o)) \;/\; Exp\,(Time \bullet B) \qquad (2)$$

where:

GR = Instantaneous growth rate (g/d)

The specific growth rate also can be calculated as:

$$SGR = (B \bullet (A - FWeight_0))/(-A + A \bullet Exp(Time \bullet B) + FWeight_0) \quad (3)$$

where:

SGR = Specific growth rate (g/g fish/d)

The SGR is found to be a function of the asymptote (A), the growth rate coefficient (B), the initial weight at stocking ($FWeight_0$), and time. The relationships are shown in Figures 2 and 3, where it can be noted that the SGR decreases very rapidly during the first 100 days of the growth period for the particular example shown. Similarly, it can be seen that the SGR value is most sensitive to changes in A and B in the lower range of the values obtained in the regressions, which is also where most of the values were obtained in both cases (75% of A values were below 250 g/fish and 70% of B values were below 0.015 L/d). Both graphs (Figures 2 and 3) are plotted for the range of A and B values obtained from the data regressions.

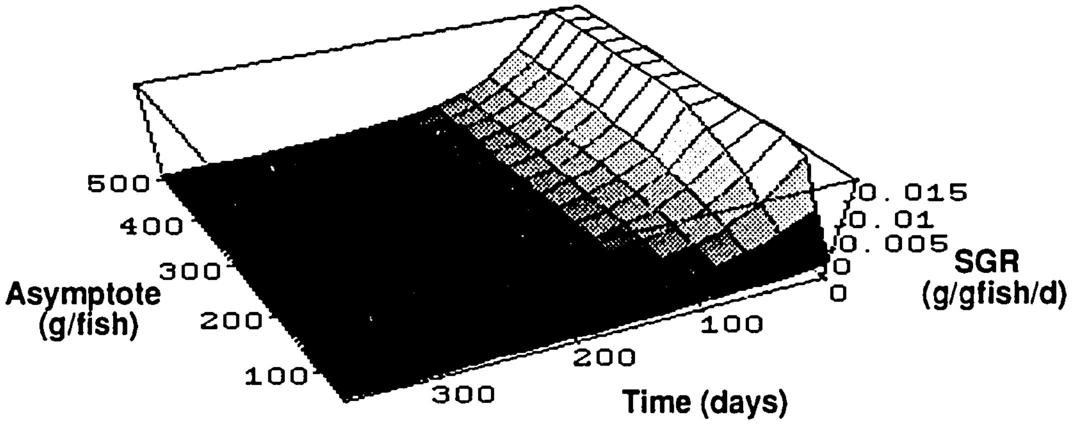

Figure 2. Specific growth rate as a function of asymptote and time for a growth rate coefficient (B) of 0.0086 1/d.

The motivation for undertaking this analysis was to be able to predict the growth rate and final weight of fish in ponds. The ability to make such predictions would enable one to estimate the duration of a growing period needed to reach a desired harvest size, or to make other similar management decisions. For example:

$$Time = Ln\,[(A - FWeight_0)/(A - FWeight)] \,/\, B \quad (4)$$

which can be plotted as in Figure 4 to show the effect of A and B on the time-to-harvest with an initial stocking weight of 37.7 g and a harvest weight of 105 g/fish. As seen in Figure 4, the time-to-harvest becomes long when the asymptotic weight and the growth rate coefficients are low.

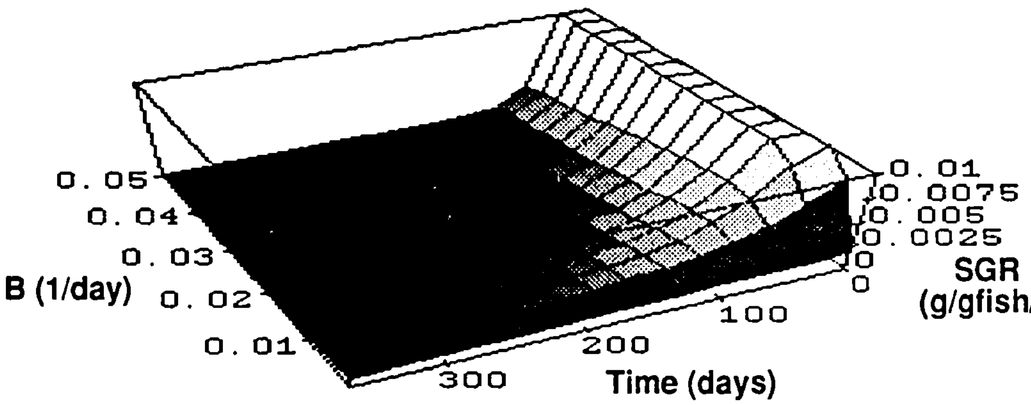

Figure 3. Specific growth rate as a function of growth rate coefficient and time for an asymptote (A) of 105 g/fish.

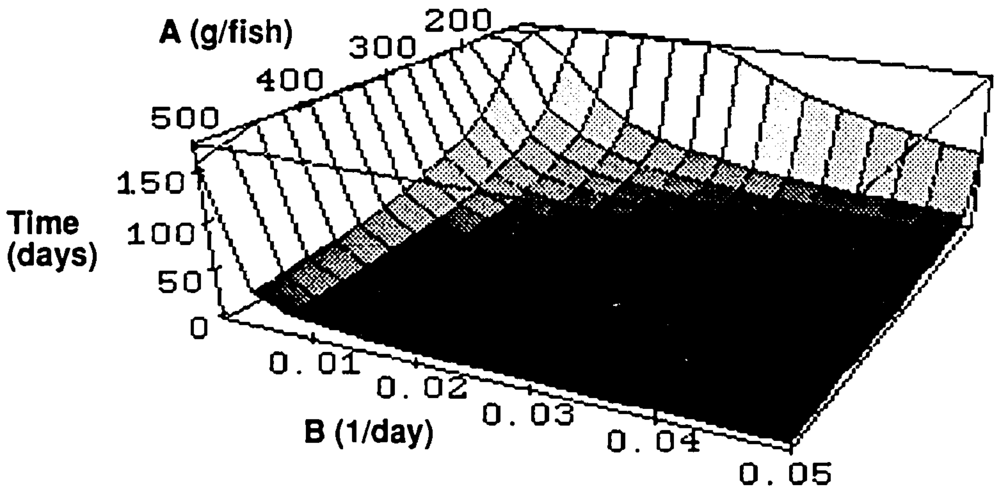

Figure 4. Effect of A and B on the time to harvest fish that are stocked at 37.7 g and are to be harvested at 105 g/fish.

In summary, there are very important and useful management implications for a fish growth model such as the one described. It is hoped that as new CRSP data are analyzed, it will be possible to make *a priori* estimates of the A and B values and make accurate growth projections that can be used in deciding the duration of a growing period or the optimum time to harvest, from the standpoint of biomass production rates or other technical or economic criteria.

DAST Study 2

Continuing on work started during the previous year, *The Aquaculture Pond* model (TAP) was used to simulate the effect of management actions on dissolved oxygen concentrations in the ponds. The hypothetical situation consisted of a reduction in solar radiation and the subsequent drop in pond dissolved oxygen. Alternative pond management practices were simulated to try to prevent the dissolved oxygen drop. The most successful management practice we tested consisted of reducing the pond depth as soon as possible. Other practices tested included flushing, fertilization, pH adjustment, and gradual depth reduction. The reason for the success of simulated pond depth reduction is that a portion of the oxygen-consuming organisms can be removed without affecting the oxygen production process. This finding has been corroborated by other simulation studies which indicate that pond depth should not be more than approximately twice the secchi disk depth. More detailed studies have been undertaken using other models, described below, to investigate the relationship between pond depth, light extinction coefficient, and primary productivity.

Although the management actions were tested in the context of a short-term crisis, they point to ways in which the dissolved oxygen climate of a pond can be optimized by maximizing oxygen production while keeping oxygen consumption low. Maintaining a shallow pond when the secchi disk depth is low will affect the temperature regime in the pond and may have effects on fish behavior or on other water quality parameters. The shallow depth will also affect the extent and frequency of stratification events occurring in a pond. It is recommended that the management of water depth by maintaining certain ratios with secchi disk depth be the subject of field trials.

Other general topics requiring further field research, as well as some specific hypotheses for possible field testing were included in the DAST Newsletter of June 1990.

DAST Study 3

A model previously developed to analyze diel dissolved oxygen data was refined and used to formulate and test hypotheses about the responses of phytoplankton to light and nutrient concentration changes. Data to test some of the hypotheses have come from the CRSP data base or have been collected in related experiments and are being analyzed. This model, based on initial data from the CRSP global data base, suggests that the "condition" of a phytoplankton population can be quantitatively assessed by analyzing the rate of change of dissolved oxygen in the pond with respect to environmental conditions. The model evaluates phytoplankton oxygen production rates as a function of temperature, light, nutrient availability, and light sensitivity. Of these four variables, temperature and light radiation are external variables that are easily and commonly measured. When temperature and light conditions are measured, the phytoplankton production model can be used to solve directly for terms quantifying the effects of nutrients and light on photosynthesis.

Using data from the CRSP data base, the *WholePond* model has been tested on a preliminary basis. The nutrient and light limitation values obtained with the model are consistent with the ranges reported in published literature.

The validated model will be useful for the analysis of future CRSP data sets, especially because the new CRSP data sets will contain several intense diel sampling runs that include detailed information about pond nutrient conditions, light intensity, and wind speed. The model will have direct application to the formulation of pond management guidelines, because phytoplankton condition and response to environmental and water quality factors can be simulated.

Efficiency of Oxygen Production

A method has been developed to calculate the whole pond oxygen production and consumption rates and the efficiency of light utilization by the phytoplankton. The method is based on a mass balance for oxygen and is explained in detail in Appendix D. The method was used to calculate oxygen production and consumption rates for all available data in the first three experimental cycles. The efficiency of light utilization for oxygen production also was calculated from the estimated oxygen production rates and the measured photosynthetically active solar radiation (PAR) at the sites.

The data needed for the computations are diel measurements of dissolved oxygen concentrations and temperatures (Template D), and the corresponding values for pond depth (Template B) and wind speed (Template A). Additional information needed for calculation of the efficiency of the utilization of solar radiation is PAR (Template A). The number of data sets available for analysis was limited to situations in which pond depth, wind speed, and PAR values were available on the same date as the diel cycles. The number of samples collected during the diel cycle has a marked effect on the calculations because oxygen consumption and production rates have to be assumed constant within each sampling time interval.

Results of the primary productivity calculations are summarized in Figures 5 through 8, where primary productivity, consumption, and efficiency are shown for the test sites and cycles.

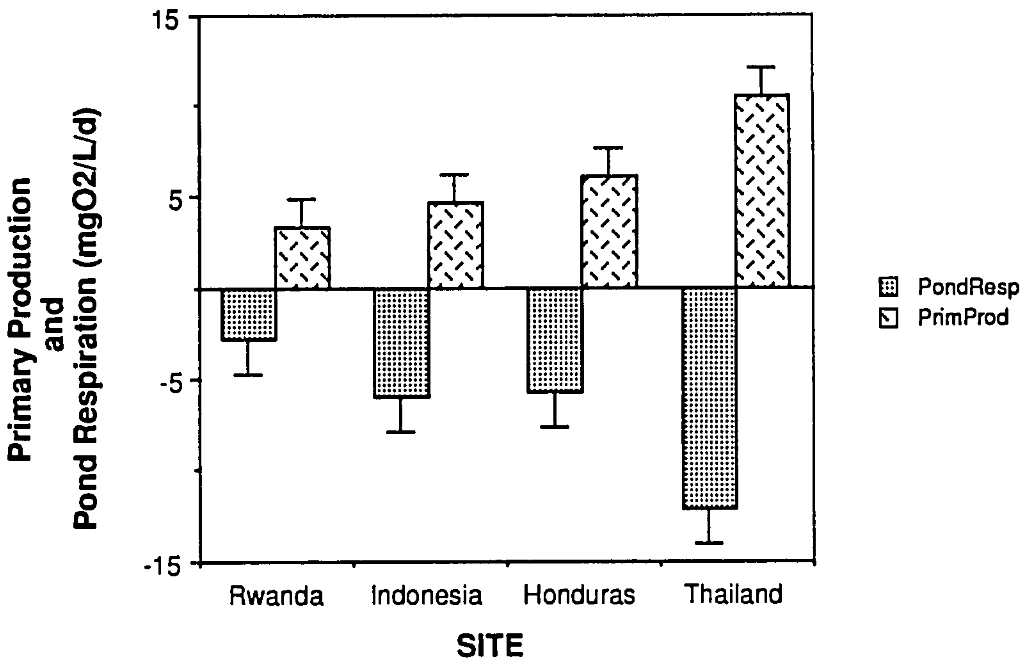

Figure 5. Primary productivity and whole pond respiration at four CRSP sites during the first three experimental cycles.

The differences between sites and between cycles are confounded by differences in treatments for which data sets were available (see Table 1). Information on the efficiency of primary productivity with respect to solar radiation could serve as an indicator of phytoplankton condition or of changes in the availability of nutrients for phytoplankton growth. Further analysis of primary productivity efficiency will be undertaken with new data sets to try to identify significant relationships between primary productivity and pond respiration under various environmental conditions and pond fertilization practices.

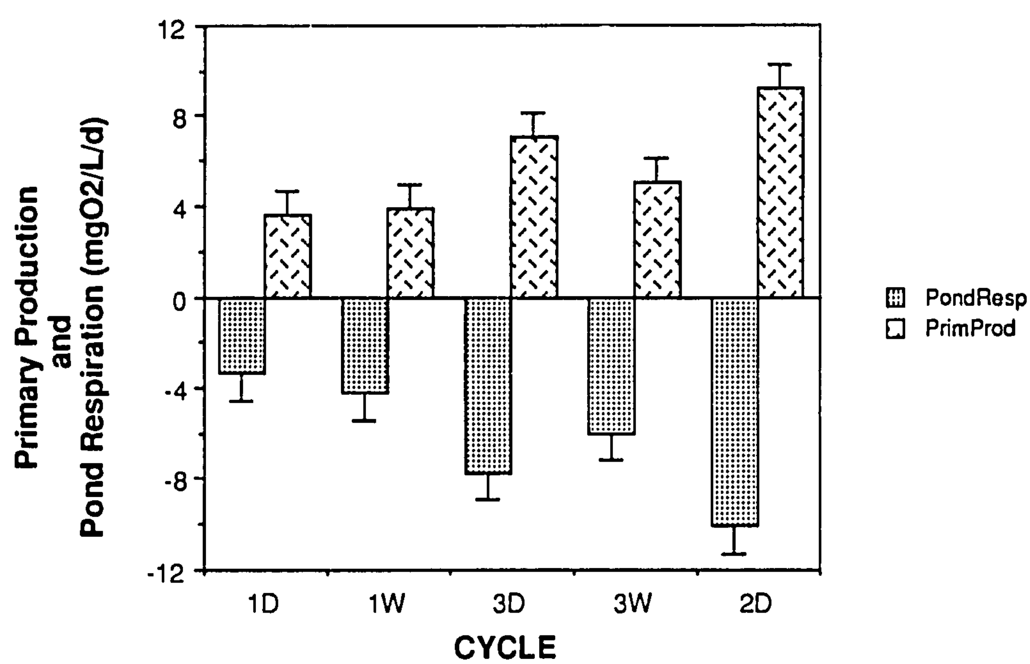

Figure 6. Primary productivity and whole pond respiration during the first three experimental cycles at four CRSP sites.

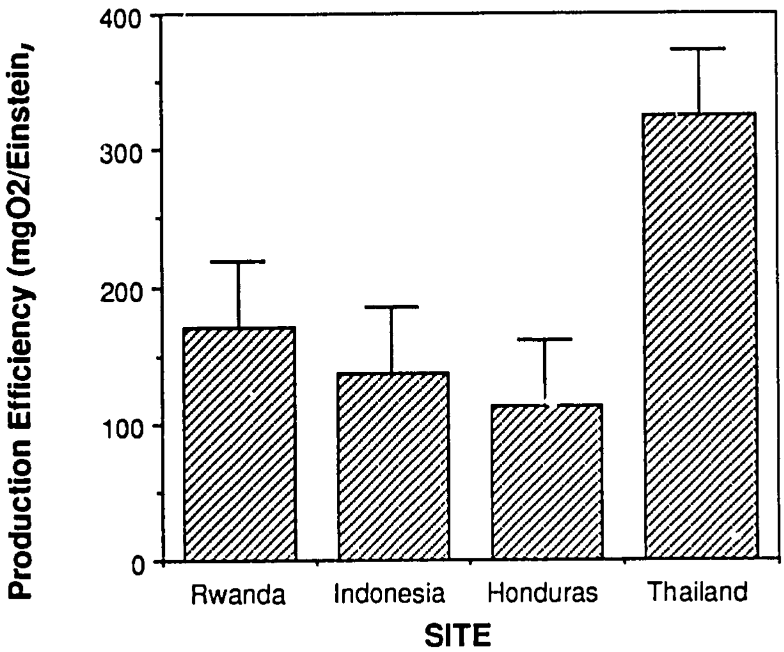

Figure 7. Efficiency of oxygen production with respect to incoming solar radiation for each site.

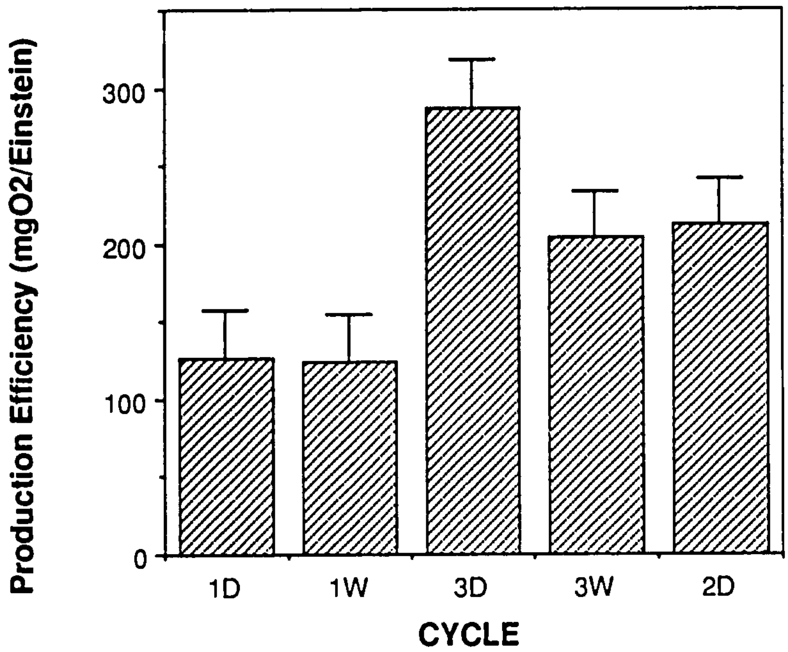

Figure 8. Efficiency of oxygen production with respect to incoming solar radiation for each cycle.

An important methods problem identified in this study is that of determining light respiration rates (distinct from simple extrapolations of dark respiration rates) in a pond for use in efficiency calculations. This problem is being investigated, and promising results have been obtained from our laboratory experiments with oxygen microprobes. Our goal is to develop an accurate, reliable technique for determining light respiration rates in the field which would result in a quantum leap in the accuracy and utility of aquaculture water quality models.

Light Saturation Changes

Analysis of primary productivity estimates obtained from dissolved oxygen mass balances and computer models based on CRSP data show that there is a high overall variability in diurnal primary productivity. From this analysis, alternative hypotheses were developed which attributed the diurnal fluctuations to changes in nutrient concentrations or to changes in the sensitivity of phytoplankton as a result of short term light adaptation.

Table 1. Sample incidence table showing the number of cases (top number in each cell) and the mean value of primary productivity (mg O_2/L/d) (bottom number in each cell) for each experimental cycle/season combination.

Site	Cycle:	1D	1W	2D	3D	3W	Totals:
Site	Rwanda	60 2.552	50 2.907	0 •	90 4.582	90 2.849	290 3.335
Site	Thailand	0 •	36 6.988	41 12.908	61 11.406	36 10.367	174 10.631
Site	Indonesia	66 4.654	71 3.147	0 •	48 6.45	59 5.311	244 4.727
Site	Honduras	0 •	0 •	48 6.128	0 •	0 •	48 6.128
Totals:		126 3.653	157 3.951	89 9.251	199 7.125	185 5.097	756 5.641

The diurnal fluctuation in photosynthetic response was not addressed in previous primary productivity models. By developing analytical procedures to calculate the degree of nutrient depletion or the degree of light adaptation over the diurnal period, we were able to show using the CRSP data base that: 1) the calculated values of nutrient depletion or light saturation were well within the range of literature values; 2) there appeared to be a different response between ponds fertilized with organic vs inorganic fertilizers; and 3) the response of phytoplankton to light changed over a diurnal cycle. In order to confirm these results, investigations have proceeded in two directions: first, a global examination of the CRSP data to confirm the observation of differential production rates between ponds receiving different fertilizer treatments, and second, an investigation into the factors involved in asymmetrical diurnal production.

Results of the examination of global production rates showed no clear patterns. However, this was primarily due to incomplete CRSP data sets. For the second investigation, the asymmetrical production rates were studied using independent data from Dr. Jim Szyper's research ponds in Hawaii. The results of this analysis showed that the light saturation value varied over time, and that it correlated significantly with the diel changes in chlorophyll *a* in the upper water column. The implications of this are significant for several reasons. First, these results contribute to our understanding of the major factors involved in the production of oxygen and plant biomass in the pond. From this information it is possible to develop much more realistic models of the aquaculture system. Secondly, from management and research perspectives, knowing that the efficiency of production is correlated to diurnal changes in chlorophyll *a* provides a means for monitoring pond production and for developing a more accurate oxygen management strategy. Finally, the development and use of these analytical techniques resulted in several quantitative theoretical tools which may be used for determining optimum parameters of pond depth and water turbidity for production.

In particular, a side benefit of this research was a set of equations for estimating the optimum light intensity for a pond. By calculating the light saturation intensity (or the optimum light) for the phytoplankton in a section of the water column, the optimum for the whole pond could be calculated. It was also noted that it appears that the optimum light for most aquaculture ponds is much higher than the available light at the sites. However, it is possible to determine the theoretical optimum depth and turbidity for production given the available light (see next section). These results hold significant potential for the development of management practices, but must be confirmed by field trials.

Models developed were also used to estimate the efficiency of the photosynthetic oxygen production process with respect to light intensity and net respiration. These efficiency values may be especially useful indicators of phytoplankton condition, or of changes in how the plankton are responding to environmental conditions. Detailed analysis of diel oxygen measurements obtained from the Hawaiian ponds has shown the need to differentiate between light and dark respiration. Respiration rates obtained from nighttime oxygen measurements appear to be not only temperature-dependent, but also time-dependent (Figure 9). Rates are particularly high soon after the sun sets, and drop substantially later on at night (e.g., after midnight), even when temperature fluctuations are minimal.

Based on the measured values of nighttime respiration, and using models developed previously (Park et al. 1985), estimates of daytime respiration rates can be made (Figure 10). The daytime respiration rates obtained with this expression are substantially higher than the nighttime values, and are consistent with published reports of increased respiratory activity during light periods (Weger et al. 1989). The use of this information in the simulation of net oxygen production is critical. Current models are normally based on respiration rates that are extrapolated from nighttime values and adjusted for temperature only. These respiration rates may underestimate the true respiration rates, resulting also in underestimation of gross primary production. Laboratory experiments are being designed and equipment tested to develop simple methods to measure light respiration rates over the diurnal cycle.

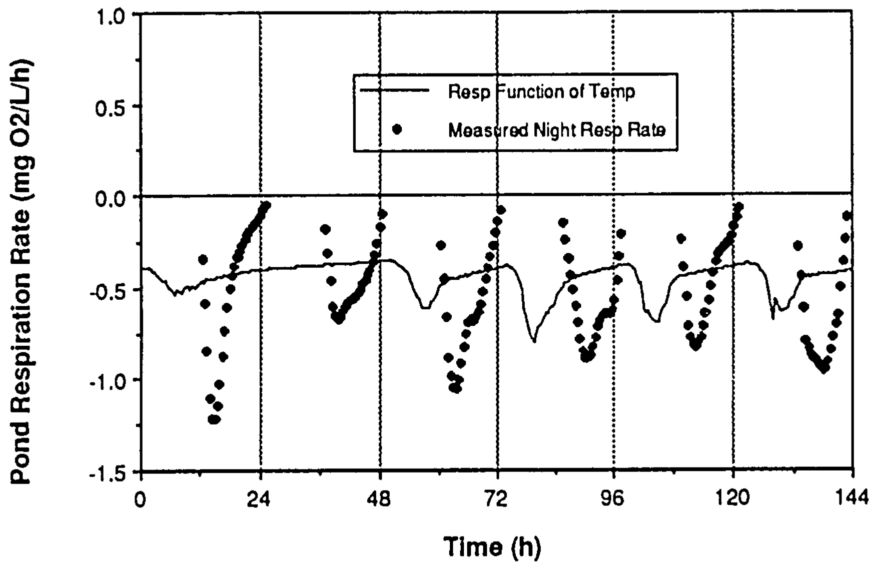

Figure 9. Graph of the observed night pond respiration rates over a six-day period vs. the pond respiration rate predicted by a commonly used temperature-dependent respiration function. The lack of correlation indicates that variables other than temperature are affecting respiration rates.

Optimization of Primary Productivity

One of the DAST goals is to develop analytical tools for aquaculture pond management. Recent research efforts have focused on considering the pond water column as a single photosynthetic unit. This approach makes possible an examination of the parameters affecting primary productivity in the photosynthetic unit. Results of the analysis are used to attempt to "design" the pond water column for optimum primary productivity.

It is well known that the difference in light environment between the surface and the deeper levels of a pond results in different primary productivity rates through the water column. The magnitude of the productivity differences depend on the depth and turbidity of the water column. Surface waters may be photoinhibited, while bottom layers may be light limited to the extent that there is no primary productivity. In addition to primary productivity, respiration must be considered in analyzing the oxygen regime in ponds and the characteristics of the relationships between depth-light extinction and oxygen concentrations.

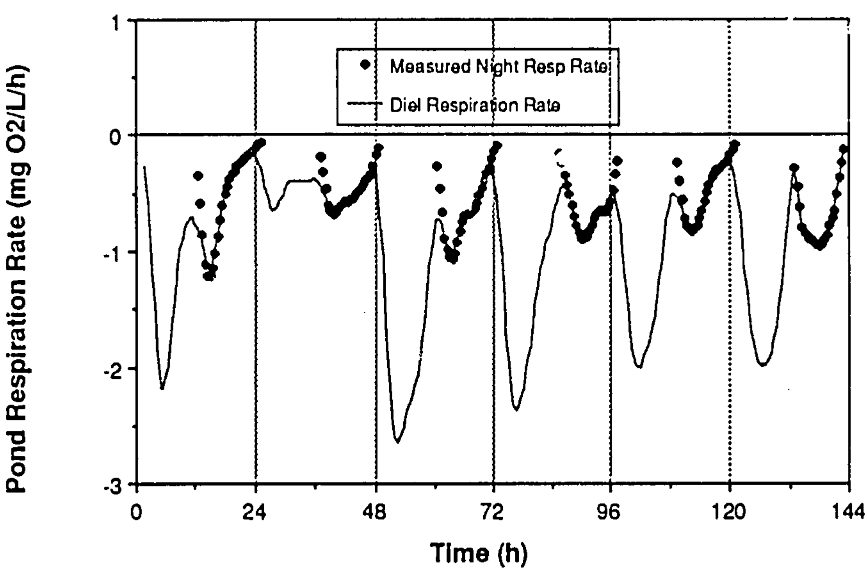

Figure 10. Observed nighttime pond respiration over a six-day period, compared with the calculated diel respiration rate. The respiration function for the light period includes two terms, a constant proportion of primary productivity and an endogenous term based on an exponential temperature-dependent function. This light respiration function is combined with the observed nighttime respiration rates as shown on the solid line.

Primary productivity may be optimized as the basis of a food chain that eventually results in fish growth, or, as done in this analysis, as the principal source of oxygen for the pond. The maintenance of healthy DO levels in a pond requires either management of the primary productivity system, or the use of emergency aeration equipment to respond to DO crises.

Recent work by the DAST provides a theoretical framework for the determination of pond design parameters for optimum primary productivity. This work, which is discussed in detail in the paper, *Phytoplankton light adaptation and production optimization in aquaculture ponds* (submitted for publication), is summarized below.

Drawing on work by Steele (1962) and Bannister (1974), a productivity equation can be formulated which describes the depth-integrated production rate in a water column.

$$Prod_z = \Phi_{max}\, k_1\, I_{sat} \left[\exp\left(-\frac{-I_o \exp(-\varepsilon z)}{I_{sat}}\right) - \exp\left(-\frac{-I_o}{I_{sat}}\right)\right] \quad (5)$$

where:

$Prod_z$	=	Total gross primary productivity (mg $O_2/m^2/h$)
Φ_{max}	=	Maximum quantum yield (3.2 mg O_2/m Einst absorbed)
k_I	=	Proportion of total light extinction due to chlorophyll *a* .
I_{sat}	=	Optimum light intensity, saturation (m Einst/m^2/s)
I_o	=	Surface light intensity (m Einst/m^2/s)
z	=	Pond depth (m)
ε	=	Light extinction coefficient (m^{-1})

The depth-integrated production (Equation 1) written in terms of areal production as a function of the light extinction coefficient (ε) and depth (z) can be evaluated as algal turbidity or pond depth increase. It is expected that production for a given light intensity will increase to the point where all incoming light is absorbed, and therefore approach an asymptotic maximum production level. To arrive at an optimum depth or turbidity value for net oxygen production, it is necessary to include a loss term due to water column respiration.

The water column respiration per unit area can be written in terms of turbidity and depth, by considering algal respiration as a first order function of chlorophyll *a* concentration:

$$\text{Algal-Resp} = \text{Chlor-a}\ k_2\ z \quad (6)$$

where:

k_2	=	Respiration constant (mg O_2/mg Chlor-a/h)
Algal Resp	=	Phytoplankton respiration (mg $O_2/m^2/h$)
Chlor-a	=	Concentration of chlorophyll-a (mg Chlor/m^3)

Since the turbidity of the water column is related to the concentration of chlorophyll pigments, it is convenient to write Chlor-a in terms of the light extinction coefficient:

$$\text{Chlor-a} = \frac{\varepsilon_{Chlor}}{K_c} \qquad (7)$$

where:

ε_{chlor} = Light extinction coefficient due to chlorophyll-a (m^{-1})
K_c = Light absorption coefficient of chlorophyll-a (m^2/mg Chlor-a)

The light extinction coefficient can be written as the sum of the light extinction coefficients due to chlorophyll-a, pure water, and suspended solids:

$$\varepsilon = \varepsilon_{chlor} + \varepsilon_{water} + \varepsilon_{sus\ solids} \qquad (8)$$

and ε_{chlor} can be expressed as a fraction of ε as indicated above:

$$\varepsilon_{chlor} = k_1 \ \varepsilon \qquad (9)$$

Combining with Equations 2 and 3 yields:

$$\text{Algal-Resp} = \frac{k_1 \ k_2 \ \varepsilon \ z}{K_c} \qquad (10)$$

The loss term from algal respiration can be added to the productivity equation (Equation 5) above, to obtain total net primary productivity:

$$\text{Prod}_z = \Phi_{max} \ k_1 \ I_{sat} \left[\exp\left(-\frac{-I_o \exp(-\varepsilon z)}{I_{sat}}\right) - \exp\left(-\frac{-I_o}{I_{sat}}\right)\right] - \frac{k_1 \ k_2 \ \varepsilon \ z}{K_c} \qquad (11)$$

This equation can be solved analytically for the optimum value of pond depth or turbidity for a given light intensity and light saturation value. However it is more convenient to determine the total daily production from Equation 11 for a diurnal light cycle corresponding to conditions similar to the site of interest. By determining daily production in this manner over a range of possible pond depths and turbidities, one can visualize the effect of changing algal turbidity (Figures 11 and 12).

From the simplified analysis presented here, one can see that maximum net oxygen production for a pond water column is reached at fairly low algal turbidities. This suggests that one can maintain relatively low phytoplankton concentrations and have near optimal dissolved oxygen production. What is important is that the phytoplankton present be growing (photosynthesizing) at high rates. This requires some efficient way of harvesting the algae to maintain the low concentrations.

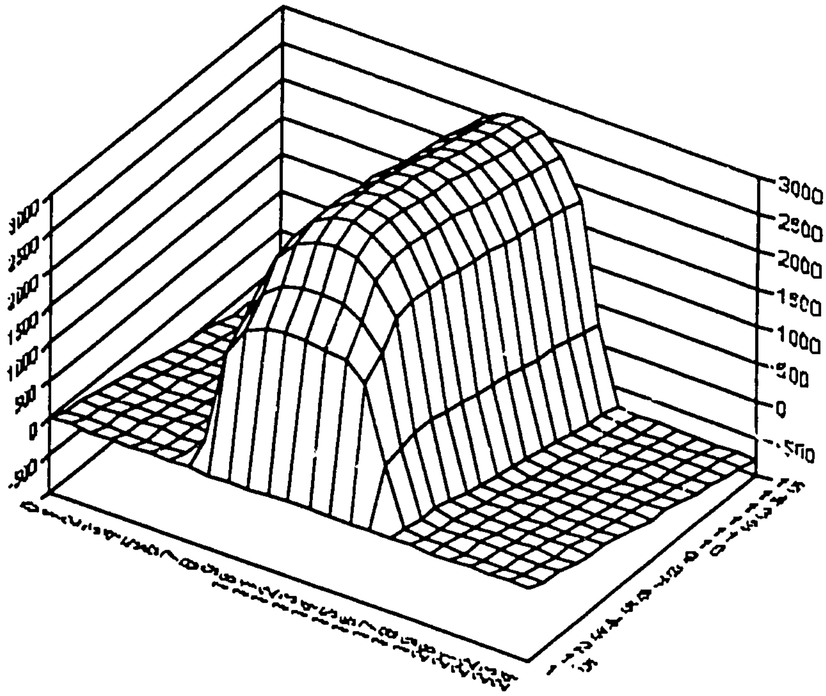

Figure 11. Net production rate (mg $O_2/m^2/hr$) (on vertical axis) as a function of time from midnight and for a light extinction coefficient ranging between 1 and 15 m^{-1}. The light extinction coefficient is an indication of algal turbidity. Respiration rate is assumed to be a function of the parameters included in Equation 10 only. Note the increase in respiration rate as turbidity increases (more "negative" production rate). At low turbidity ($\varepsilon = 1$) no algae are present in the water column, consequently no production or respiration occurs.

High phytoplankton concentrations (or high algal turbidities) can result in decreasing net oxygen available in the ponds. Similar analyses can be made for changes in pond depth, to show the relationship between pond depth and the light extinction coefficient. In managing the dissolved oxygen in ponds, one needs to take into account both water column depth and the light extinction coefficient. The changes in other water quality parameters, such as temperature, and in stratification caused by adjustments in pond depth and the light extinction coefficient, need to be investigated before making detailed recommendations.

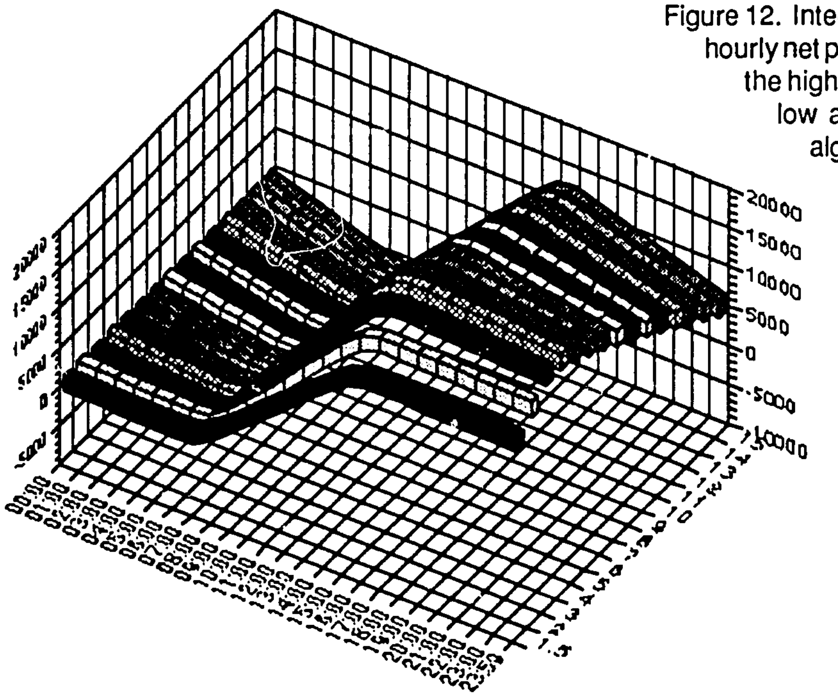

Figure 12. Integral over a day (starting at midnight) of hourly net production rates (mg O_2/m^2). Note that the highest daily net production occurs at fairly low algal turbidities and declines for high algal turbidities.

References

Bannister, T.T. 1974. Production equations in terms of chlorophyll concentration, quantum yield, and upper limit to production. Limnology and Oceanography 19:1-12.

Park, R.A., B. Indyke, B.B. Macleod, C.D. Collins, and J.R. Abanese. 1985. Documentation of the aquatic ecosystem model MINI.CLEANER. U.S.E.P.A., Athens, Georgia.

Steele, J.H. 1962. Environmental control of photosynthesis in the sea. Limnology and Oceanography 7:137-150.

Weger, H.G., R. Herzig, P.G. Falowski, and D.H. Turpin. 1989. Respiratory losses in the light in a marine diatom: measurements by short-term mass spectrometry. Limnology and Oceanography 34:1153-1161.

Provisional Guidelines for Fertilizing Aquaculture Ponds

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Introduction

During this reporting period, the Oregon State University (OSU) component of the DAST focused on the preparation of guidelines for fertilizing aquaculture ponds. This year was the final year of a three-year project intended to synthesize and translate CRSP research findings into practical fish culture procedures, and culminated in the development of *Provisional Guidelines For Fertilizing Aquaculture Ponds*. The *Guidelines* were demonstrated to CRSP participants at the 1990 annual meeting of the CRSP Technical Committee, and are being distributed to CRSP participants for review.

The *Guidelines* are based primarily on a synthesis of CRSP research and other recent contributions to the study of pond dynamics. Although recent research findings have resulted in rapid growth of our understanding of pond processes, there are still many voids in the information base required to produce comprehensive management guidelines. Therefore, several ancillary studies were undertaken. These studies include:

1. Development of a simple procedure for estimating the lime requirements of pond soils in cases where soil testing facilities are not available or capabilities are limited,
2. Estimation of the primary nutrients (N, P) available from various animal manures and other potential fertilizers, and
3. Development of computational procedures for determining the most cost-efficient fertilizer or combination of fertilizers which will satisfy the requirement for primary nutrients of a specified pond environment.

Previous Work

Earlier phases of this project focused on how to best organize research information for translation into practical management guidelines. The approach taken for organizing the research information was to develop a functional classification of pond ecosystems according to the fertilization practices that have the highest probability for optimizing fish yield, and developing quantitative functional relationships that describe the appropriate levels and frequencies of application of the various practices for each class. A hierarchical classification of tropical farm ponds was developed. Ponds are classified according to source water chemistry, soil properties, and climatic factors. There is a unique set of corresponding fertilization requirements for each class.

The "shell" of an "expert system" was developed to compile the information for dissemination to interested audiences. The expert system is a computer program that identifies the class to which a pond belongs and calculates the requirements for primary nutrients of a typical pond in that class. If data are available for a specific pond, the user may enter the local data to override the typical values. The program then calculates the levels of nutrients required for the pond and the amount of a specified fertilizer that satisfies the nutrient requirement. It also calculates the most efficient combinations of fertilizers that satisfy the nutrient requirements, based on local costs provided by the user.

The expert system used with the pond classification model, named PONDCLASS, is designed to be run on personal computers. Two versions of PONDCLASS were developed—one for the IBM-PC and compatible hardware, and one for the Apple Macintosh computer.

Objectives

Activities at OSU during the 1989-90 year addressed Objective 3 of the DAST goals and objectives stated in the Fifth Work Plan:

3. To develop methods and tools for disseminating pond management guidelines based on CRSP research findings.

The DAST activity related to Objective 3 is described as DAST STUDY 4 in the Work Plan. The objectives of the Study are:

1. To complete the development of a functional system for classifying ponds according to ecological variables and fertilization practices that have the highest probability of improving fish yields;
2. To develop quantitative relationships that describe the appropriate levels and frequencies of fertilization for each pond category;
3. To integrate the classification model and functional relationships into an expert system;
4. To compile the organized information into a manual of farm fertilization guidelines; and
5. To verify the guidelines contained in the model.

Results

The activities addressing DAST Objective 3 in the Fifth Work Plan have resulted in tangible progress in developing pond management practices, including preparation of *Provisional Guidelines*, and have provided essential information related to the estimation of lime requirements, the availability of primary nutrients from various fertilizers, and least-cost fertilizer regimes. Additional detail is provided below for each of these project activities.

Guidelines

Provisional Guidelines is a manual of procedures for calculating the fertilizer requirements of aquaculture ponds. The rationale for the *Guidelines* is that the appropriate amounts of fertilizers to be added to a given pond are determined by dynamic interactions of physical, chemical, and biological processes occurring in the pond. It follows that ponds with similar environments will require similar fertilization regimes, and that the fertilization requirements of any two ponds will become increasingly disparate as the pond environments diverge from one another. The nature and extent of pond processes may be estimated from the observed values of certain pond variables, and the requirement for fertilizer addition may be calculated from these estimates. If empirical values are not available for a certain pond, reasonable approximations may be inferred from knowledge of local source waters, soils, and climatic conditions.

The *Guidelines* explain methods for the calculation of fertilization requirements. However, the calculations are cumbersome because of the large number of variables and the complexity of the interactions. To simplify the calculations and extend their utility to a larger audience, the *Guidelines* also include an expert system named PONDCLASS. The expert system is a computer program that estimates the requirements of a given pond for primary nutrients, and then calculates the most efficient (i.e., least-cost) combination of fertilizers which will satisfy those requirements, based on local costs of fertilizers. Versions of PONDCLASS have been written for IBM-PC and Apple Macintosh personal computers.

At the present stage of development, the *Guidelines* must be considered provisional. Although the *Guidelines* are based on a synthesis of current understanding of pond processes, they have not been thoroughly tested in production situations in the field. Additionally, the information base still contains significant voids, and some of the information required to develop comprehensive guidelines is not presently available. Thus it has been necessary to rely on heuristic modeling techniques to estimate some key parameters used in the initial synthesis. Indeed, one benefit of the *Provisional Guidelines* is the identification of information voids and research needs.

Organization of the *Provisional Guidelines*. The *Guidelines* are organized to address three different aquacultural audiences; (i) planners, (ii) producers, and (iii) scientists and students. Calculations tailored to the needs of each audience are included in the *Guidelines*, and in the PONDCLASS program. In PONDCLASS, the functions which address the three audiences are named, respectively, Planner, Manager, and Simulator (Figure 1). Each function is described in additional detail below.

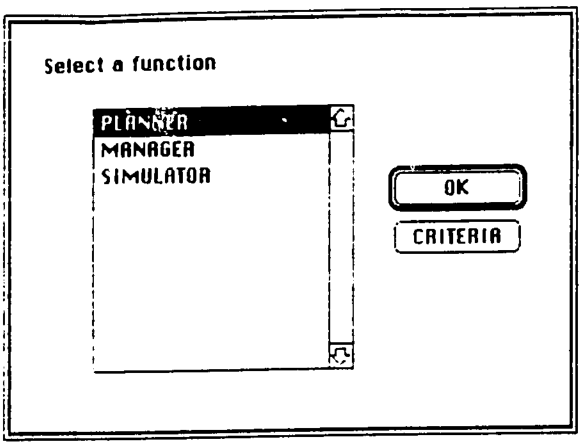

Figure 1. The PONDCLASS function selector (Macintosh version).

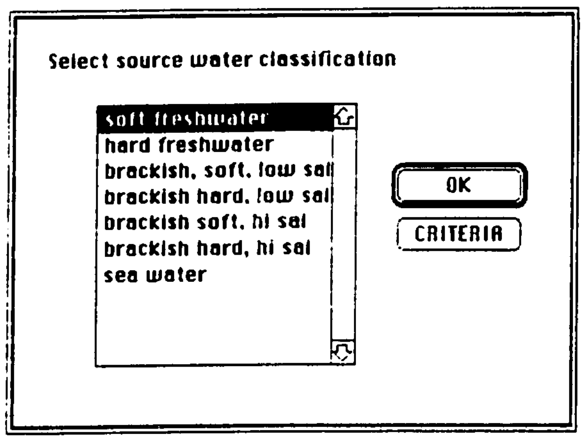

Figure 2. The source water classification selector in PONDCLASS (Macintosh version).

Planner, Manager, and Simulator all operate on the same principles, and only the inputs and outputs differ to suit the needs of the intended audience. In each case, the first operating step is to establish a data file for the pond being planned, managed, or simulated. A data file is established by classifying the pond according to source water, pond soil, and climatic characteristics (Figure 2). The *Guidelines* return values for key variables in a pond typical of the class. The value of each variable may then be overridden if local data for the specific pond are available; the typical values may be used if any or all data are not available (Figure 3).

Following creation of a data file, the user provides information about the fertilizers being considered (Figure 4). The information includes the type and form and the local costs of the fertilizer(s). Information for up to three fertilizers may be specified. The *Guidelines* return typical values for available dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP) and biological oxygen demand for each fertilizer. As was the case with pond variables, these values may be edited by the user if local data are available.

The final step involves the actual calculations of the requirements for primary nutrients, and the most efficient fertilizer regime that will satisfy the requirements. The algorithm used in the calculations is based on CRSP research findings reported by Md. Yusoff and McNabb (1989) and McNabb et. al. (1990). The results of the calculations are presented in forms appropriate for the function (i.e., Planner, Manager, or Simulator) (Figure 5).

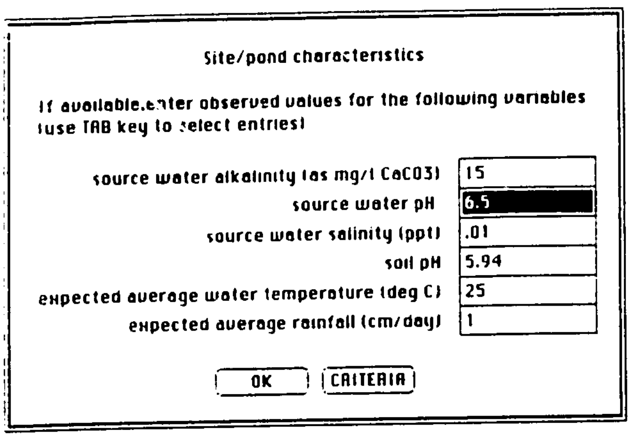

Figure 3. Typical PONDCLASS data input screen (Macintosh version).

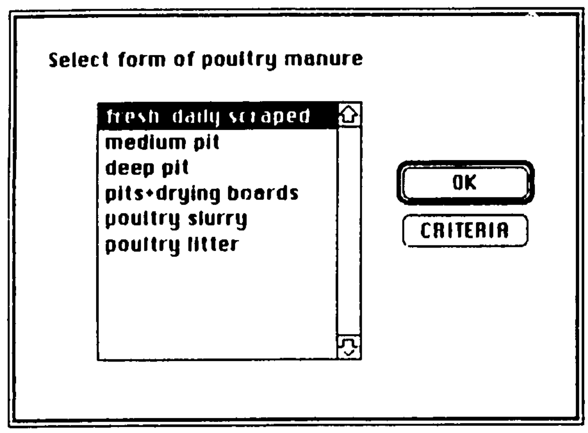

Figure 4. PONDCLASS fertilizer selector (Macintosh version).

The PONDCLASS program provides the user with the opportunity to experiment with any number of fertilizer combinations without having to re-enter pond data. Additionally, each function incorporates special features which are tailored to the intended application. These features are described below.

Planner. One application for the *Guidelines* is often encountered by planners considering the question of whether pond aquaculture is an economically viable alternative for a particular community, country, or region. Among other kinds of information required, the planner needs to know the expected production costs and benefits. But this information may be difficult or impossible to obtain, because ponds may not exist. The Planner function bases calculations on a fictitious pond typical of the local area. Local data may be used if available; otherwise, analyses may be conducted using typical values. Because ponds may not exist, outputs are standardized for a pond of one

```
FERTILIZER OPTIMIZATION
Optimal Combination of Selected Fertilizers:
 1. Type: poultry manure        form: fresh/daily scraped
    Use .313712  kg/m3/day: ( 1076.14  kg/week for this pond)
 2. Type: synthetic nits        form: urea
    Use 0  kg/m3/day: ( 0  kg/week for this pond)
 3. Type: synthetic phos        form: superphosphate-0
    Use 0  kg/m3/day: ( 0  kg/week for this pond)

Nutrients (g/m3/day) provided by optimal application:
  Nutrient          Required      Provided       Excess
  Nitrogen          - .130        4.549          4.679
  Phosphorus        1.631         1.631          - .000
  BOD               .380          16.313         15.933

Daily cost of optimal fertilizer mix for this pond:  61.4938
```

Figure 5. Example of a PONDCLASS output report. In this example, the nitrogen and phosphorus requirements are optimally satisfied by chicken manure alone; mixing manure and inorganic sources of nitrogen and phosphorus does not improve cost efficiency.

hectare surface area. The planner may scale the values up or down as dictated by local needs.

Manager. The Manager function is a tool for improving the production efficiency in real ponds. Although Manager is intended to benefit farmers, it is more likely to be used by extension personnel and others who advise farmers.

Unlike Planner, Manager is intended to calculate requirements for a real pond. Thus the input requirements include pond dimensions, dates, and other information required to adjust the calculations for actual pond conditions and changes in pond volume. Because the Manager function describes a real pond, the outputs are calibrated in terms of requirements of the actual pond rather than per unit surface area (e.g., per hectare).

The Manager function provides information for adaptive pond management. Calculations based on the initial data entries result in recommendations for the amendments required at the beginning of a production cycle. Subsequently the values of the key variables used in the Manager function may be determined in the pond at weekly intervals, and the data files may be routinely updated. A procedure for interpreting the trends in the variables is provided, so that the response of the pond to the amendments may be continuously observed and adjusted to establish and maintain optimum pond conditions. Thus the Manager function provides a means of checking the reliability of the *Guidelines*.

The Manager function also incorporates a function for maintaining weekly records on the pond water budget. The algorithm used to calculate pond nutrient requirements assumes that water losses due to seepage are negligible. However, ponds are often observed to lose substantial volumes of water due to seepage. Such water losses may result in alterations of pond processes such that the recommended amendments may not be effective. The Water Budget "utility" provides a means of estimating seepage loses, so that appropriate adjustments to fertilizer additions may be made.

Simulator. The Simulator function operates like the Planner function except that the values for most variables, constants, and parameters may be viewed and edited by the user. This provides scientists and students with a way to observe how the numerical values of the variables, constants, or parameters influence the fertilizer requirements. For example, one may run a simulation with a specified set of values and observe the outputs, then change one or more values and compare the outputs to the former case.

Lime Requirements

The application of lime to aquaculture ponds may improve fish yields in many cases. The benefits of liming result from reduction of soil acidity and loss of primary nutrients to the muds, and from enhancement of alkalinity. The *Guidelines* include provisions for identifying cases where liming is likely to be beneficial and estimating their lime requirements. The algorithm used to estimate lime requirements is based on the methods employed to estimate lime requirements for agricultural soils (Peech, 1965). The basic equation is: LR = CEC X (desired PBS - initial PBS) X CR,

where:

CEC	=	Cation Exchange Capacity of the soil,
PBS	=	Percent Base Saturation of the soil, and
CR	=	a correction term which adjusts for the mass of soil to be limed.

The lime requirement can be calculated directly using this relationship if values for CEC and PBS are available. However, determination of CEC and PBS requires analytical methods which may not be accessible. In cases where CEC and PBS are unavailable but limited laboratory capabilities are accessible, shortcut titration procedures such as those proposed by Boyd (1979) and Pillai and Boyd (1985) may be used.

We have attempted to avoid making the use of the *Guidelines* be dependent on laboratory analyses. Therefore, we initiated a project activity to develop a method for estimating lime requirements in those cases where laboratory analysis of soils is not available. The approach taken was to extract a database from published soils literature. The database includes values of CEC, soil pH, and PBS for a large number of soils representing various soil types. These data were used to develop empirical estimates of CEC, and the pH-PBS relationships for the several soil groups. These estimated values permit calculation of the expected lime requirement given knowledge of soil type and a simple field determination of initial soil pH (Bowman and Lannan, manuscript in preparation). An empirical model of a titration curve for one soil group is shown in Figure 6.

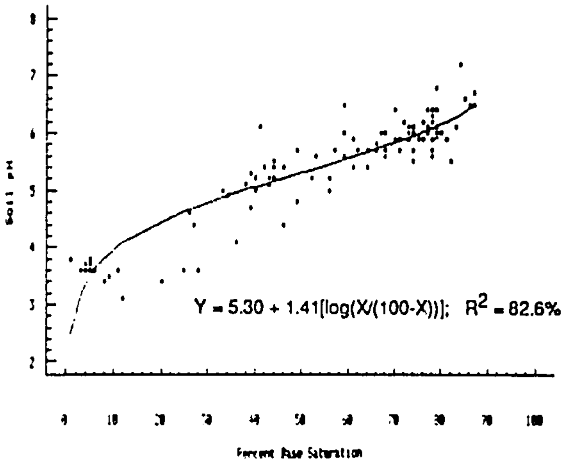

Figure 6. Empirical model of a titration curve for a soil group.

Availability of Primary Nutrients from Fertilizers

Effective guidelines for using animal manures to fertilize ponds would have to take into account the nitrogen and phosphorus contents of different animal wastes, the proportion of the nitrogen and phosphorus content that would be available as DIN and DIP, and the BOD (biochemical oxygen demand) contributed to the system by the addition of manure. Unfortunately, there is a paucity of this type of information in the published aquaculture literature. Therefore, a study was initiated to determine provisional values for these parameters for use in the *Guidelines*.

Contents of Animal Manures. The approach taken for determining the contents of animal manures was to construct a database of values for dry matter (DM), total nitrogen (TN), total phosphorus (TP), and 5-day BOD (all as percentages of wet weight) reported in the published agricultural literature for various animal manures. The database was used to determine typical values of these variables (means and standard deviations) for manures of different types, and for different storage conditions (forms) within types. Provisional values for total nitrogen and phosphorus contents of various types and forms of manures are shown in Tables 1-5 (Nath and Lannan, manuscript in preparation).

Table 1. Dry matter (DM), Total nitrogen (TN), Total phosphorus (TP) and 5-day BOD (as % wet wt.) values for different poultry wastes.

FORM	DM	TN	TP	BOD
1. Fresh	24.0 ± 6.0[a] (45)[b]	1.45 ± 0.35 (38)	0.52 ± 0.19 (17)	5.2 ± 2.9 (11)
2. Manure from medium pits (< 2 ft. deep)	42.0 ± 22.0 (5)	1.30 ± 0.70 (5)	1.10 ± 0.80 (5)	6.4 ± 3.8 (3)
3. Manure from deep pits (> 2 ft. deep)	55.0 + 21.0 (8)	2.00 ± 1.00 (5)	1.20 ± 0.30 (3)	8.38[c]
4. Manure from pits with drying boards	44.0 ± 10.0 (8)	1.80 ± 1.20 (5)	0.91 ± 0.62 (4)	6.70[c]
5. Poultry slurry	8.2 ± 4.0 (4)	0.64 ± 0.20 (10)	0.33 ± 0.25 (7)	4.5 (1)
6. Poultry litter	72.0 ± 3.5 (33)	2.80 ± 0.90 (37)	1.20 ± 0.50 (34)	10.97[c]

[a] Mean ± 1 Standard deviation; [b] Number of sources from which data were collected;
[c] Estimated from BOD (of form 2 above) and DM data, assuming BOD:DM to be approximately constant .

Table 2. Dry matter (DM), Total nitrogen (TN), Total phosphorus (TP) and 5-day BOD (as % wet wt.) values for different swine wastes.

FORM	DM	TN	TP	BOD
1. Fresh/scraped	10.7 ± 4.5[a] (54)[b]	0.64	0.21	3.40
2. Concrete slab facilities	7.9	0.51	0.19	3.16
3. Slotted floor pit systems	4.8	0.34	0.12	1.92
4. Farmyard manure 54-98 (Range)	79 (Median)	2.29	1.00	na

[a] Mean ± 1 Standard deviation; [b] Number of data points; na: Data not available

Table 3. Dry matter (DM), Total nitrogen (TN), Total phosphorus (TP) and 5-day BOD (as % wet wt.) values for different beef wastes.

FORM	DM	TN	TP	BOD
1. Fresh/scraped	14.8 ± 3.7[a] (17)[b]	0.59 ± 0.16 (10)	0.14 ± 0.07 (13)	2.5 ± 1.3 (15)
2. Pit stored	12.0 ± 7.3 (11)	0.42 ± 0.12 (20)	0.13 ± 0.06 (15)	2.5 ± 1.3 (15)
3. Wastes + Bedding	16.7 ± 6.3 (3)	0.62 ± 0.14 (10)	0.21 ± 0.10 (5)	2.82[c]
4. Feedlot solids	56.0 ± 15.5 (32)	1.00 ± 0.66 (20)	0.32 ± 0.26 (17)	5.3 ± 4.5 (2)
5. Farmyard manure	21 (Median) 14-36 (Range) (12)	0.6 (12)	0.4 (12)	3.55[c]

[a] Mean ± 1 Standard deviation;

[b] Number of sources from which data were collected;

[c] Estimated from BOD (of form 1 above) and DM data, assuming BOD:DM to be approximately constant.

Table 4. Dry matter (DM), Total nitrogen (TN), Total phosphorus (TP) and 5-day BOD (as % wet wt.) values for different dairy wastes.

FORM	DM	TN	TP	BOD
1. Fresh/scraped	13.6 + 3.4[a] (21)[b]	0.48 + 0.10 (23)	0.12 + 0.05 (45)	1.5 + 0.5 (5)
2. Pit stored	7.9 ± 3.4 (7)	0.36 ± 0.17 (24)	0.07 ± 0.06 (12)	0.56 ± 0.26 (3)
3. Loose housing + Bedding	28.0 + 7.8 (3)	0.70[c]	0.18 ± 0.06 (4)	3.09[d]
4. Feedlot solids	66 (1)	1.85[c]	0.33[c]	7.28[d]
5. Farmyard manure	21 (Median) 14-36 (Range) (12)	0.6 (12)	0.4 (12)	2.32[d]

[a] Mean ± 1 Standard deviation;

[b] Number of sources from which data were collected;

[c] Calculated from TN/TP data expressed in terms of DM, using average DM% for the specific form;

[d] Estimated from BOD (of form 1 above) and DM data, assuming BOD:DM to be approximately constant.

Table 5. Dry matter (DM), Total nitrogen (TN), Total phosphorus (TP) and 5-day BOD (as % wet wt.) values for miscellaneous manures.

MANURE TYPE	DM	TN	TP	BOD
1. Turkey	25.5	1.32	0.49	4.47
2. Duck	28.2	1.36	0.49	4.09
3. Horse	29.4	0.59	0.14	3.33
4. Sheep	27.5	1.05	0.22	3.00
5. Goat	31.7	1.1	0.27	na
6. Goose	23.0	0.6	0.22	na
7. Rabbit	58.0	1.72	1.30	3.87

Available DIN and DIP. Laboratory experiments were conducted to determine the amount of nitrogen and phosphorus that becomes available as DIN and DIP when manures are added to water. Among DIN forms (NH_3-N, NO_3-N and NO_2-N), substantial changes occurred only in the NH_3-N form. Manures typically showed highest mean NH_3-N concentrations on the fifth day after manure addition, followed by a drastic decline in NH_3-N levels (Figure 7). Mean DIP concentrations were also highest on the fifth day (Figure 8). Following a steep decline after this period, the DIP levels began to gradually increase towards the end of the experiment.

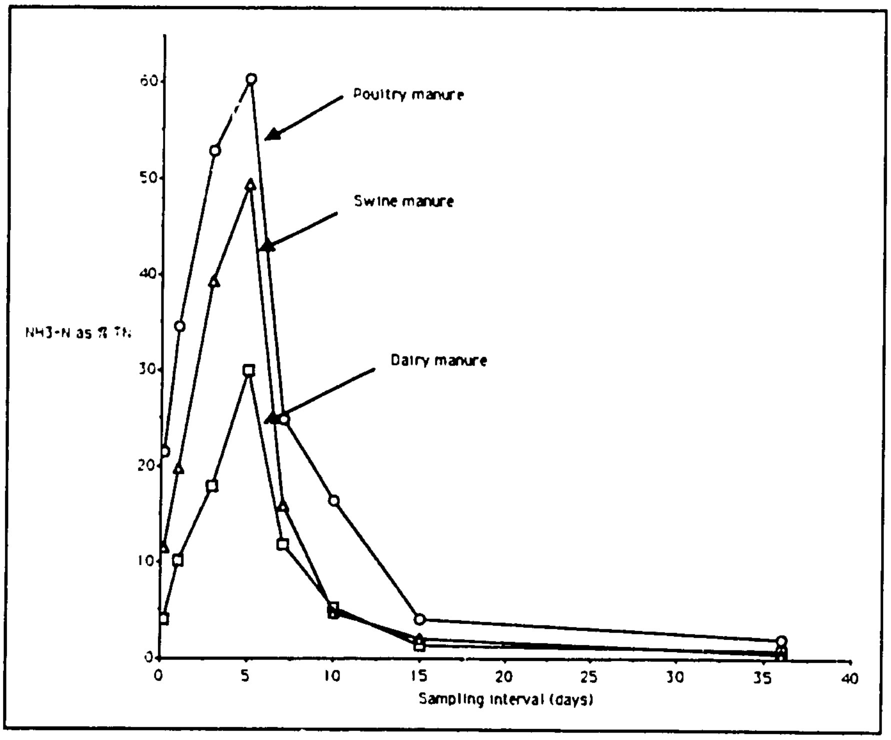

Figure 7. Observed patterns of ammonia nitrogen (NH_3-N) (as percent of total nitrogen in manure) versus time when samples of various animal manures were placed in water.

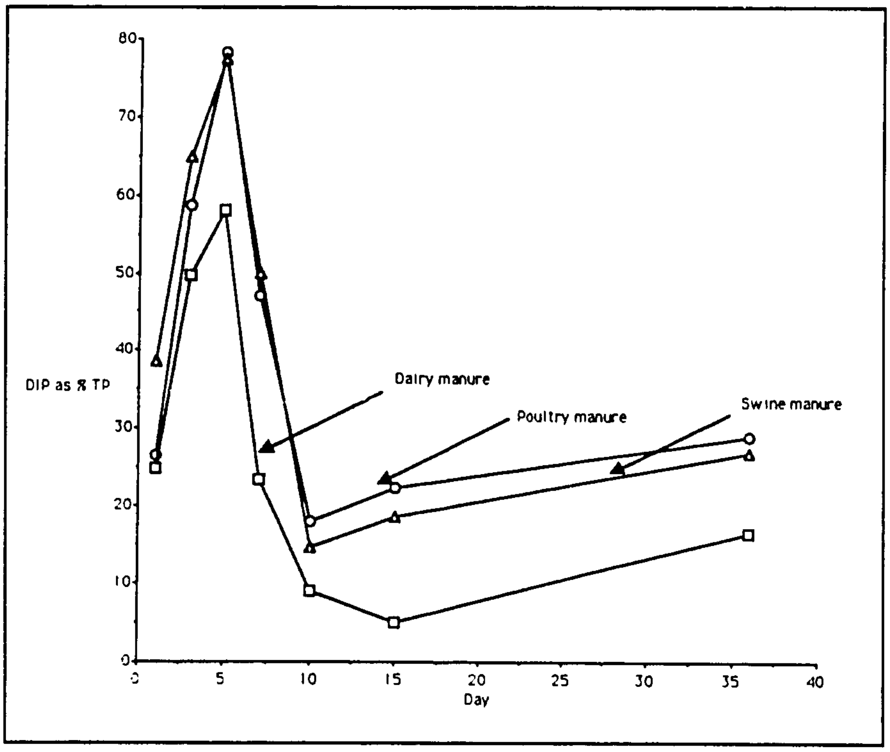

Figure 8. Observed patterns of dissolved inorganic phosphorus (as percent of total phosphorus in manure) versus time when samples of various animal manures were placed in water.

Provisional values for available DIN and DIP. Although these results must be considered preliminary, they serve to illustrate that in the context of pond fertilization guidelines, consideration must be given to the *available*, and not only the *total* nitrogen and phosphorus contents of organic wastes. Additional research is needed to produce more comprehensive guidelines for pond fertilization. Until more comprehensive information becomes available, we suggest using the coefficients 0.60, 0.50, and 0.30 of the total nitrogen content of the fertilizer (percent dry weight), and 0.80, 0.80, and 0.60 of the total phosphorus content of the fertilizer (percent dry weight), to estimate available DIN and DIP for poultry, swine, and cattle manures, respectively.

Least-Cost Fertilization

In many aquaculture applications, farmers have more than one fertilizer option for satisfying the pond nutrient requirements. The preferred option is usually the one that satisfies the requirements for the least cost. In some cases, the use of a single fertilizer will be indicated. However, in many cases, combinations of two or more fertilizers will be more cost effective than any single fertilizer.

Because the goal of the CRSP is to improve the *efficiency* of pond aquaculture, it is imperative that the *Guidelines* include provisions for the efficient use of fertilizers. For this reason, a study was initiated to (i) explore alternative optimization methods, including linear programming techniques, and (ii) to develop or adapt an appropriate algorithm for use in PONDCLASS. The linear programming technique known as the *simplex method* was selected, and a computer program using this method has been written and incorporated into PONDCLASS. A sample output of the *simplex* function is shown in Figure 5.

References

Boyd, C.E. 1979. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station, Auburn University, Alabama. 35 pp.

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. Pages 169-172 *in* R. Hirano and I. Hanyu, editors. The Second Asian Fisheries Forum. The Asian Fisheries Society, Manila, Philippines.

Md. Yusoff, F. and C. D. McNabb. 1989. Effects of nutrient availability on primary productivity and fish production in fertilized tropical ponds. Aquaculture 78:303-319.

Peech, M. 1965. Lime requirement. Chapter 61 *in* C.A. Black, editor. Methods of soil analysis. American Society of Agronomy. Madison, Wisconsin. 1572 pp.

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

VI. Host Country Special Topics Research

Introduction

This component of the Pond Dynamics/Aquaculture CRSP was created to provide opportunities for host country and U.S. researchers to collaborate on original research directed towards the needs and priorities of each host country. The intent is to strengthen linkages within the host country institution and to contribute to the development of research capabilities within the institution 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 shorter term local problems. Projects focus on specific aspects of the Global Experiment that would benefit from site-specific, detailed investigations. They complement the U.S.-based Special Topics Research Projects.

Proposals for these Special Topics Research Projects are developed collaboratively by the host country and U.S. scientists. The proposals are endorsed by the host country institution and are reviewed by the CRSP Board of Directors for technical merit and relevance to the general goals of the CRSP. The Board also requires that investigators discuss the proposed project with USAID Missions to ensure that the projects are consistent with USAID and host country development strategies and priorities.

Although the special topics projects are an important part of the CRSP, they are not a major component in terms of funding support or time expenditures. Twenty to twenty-five percent of each research associate's time typically is devoted to this activity. The CRSP places highest priority on the long-term research defined as the Global Experiment. Host country agencies and institutions and USAID Missions, however, often consider such basic research activities to be of low priority. Consequently, administrators sometimes have difficulty justifying participation in the CRSP. The CRSP support for the Special Topics Research activities helps to justify this participation.

Comparative Growth and Mortality of *Oreochromis niloticus* and *Clarias gariepinus* Fingerlings

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Introduction

Oreochromis niloticus (Nile tilapia) is the only fish cultured by fish farmers in Rwanda. *Clarias gariepinus* is widely utilized in other African countries for the control of overproduction of tilapia fingerlings. However, at high elevations unwanted reproduction is somewhat controlled by low temperatures. Research to compare the growth performance of these two species in Rwanda has not been previously conducted.

Objectives

The objective of this study was to compare the growth rates of *C. gariepinus* and *O. niloticus* fingerlings of similar initial weights under conditions of identical stocking densities and organic fertilization regimes and in simultaneous culture with adult *O. niloticus.*

Materials and Methods

The experiment was conducted for 93 days in eight ponds of 7 ares (1 are = 0.01 ha) each (2 treatments with 4 replicates). Adult *O. niloticus* males weighing an average of 120 g were stocked at a density of 50 fish per are. Four of the ponds were also stocked with tilapia fingerlings weighing 4 g each (treatment ON-ON) and the remaining four ponds were stocked with *Clarias* fingerlings weighing 3 g each (treatment ON-CG). Fingerlings were stocked in all ponds at a density of 100 fish per are. Every 4 weeks at least 30 adults and fingerlings were counted and weighed, and five fingerlings from each pond were removed for stomach analysis.

All ponds were fertilized with a 2:1 mixture of freshly cut grass and chicken litter at a rate of 300 kg/ha/wk as dry weight (Veverica et al. 1989, Rurangwa et al. 1989). Rice bran was added daily at 10% body weight up to a maximum of 5 g/fish. Equal quantities were distributed in all the ponds based on the mean weight of fingerlings and adults.

Results

After 93 days, the average weights and standing crops of adult tilapia were similar in the two treatments: 203-204 g and 1001-1003 kg/ha (Figure 1). The survival of adult fish in the two treatments was also similar.

The final average weight and the net yield of *Clarias* fingerlings were significantly greater than those of tilapia fingerlings: 56 g and 471 kg/ha for *Clarias* and 34 g and 220 kg/ha for tilapia (Figure 2). The average survival of *Clarias* fingerlings (91%) was not significantly greater than that of tilapia fingerlings (76%).

The total net production of the ON-CG treatment was 40% greater than that of the ON-ON treatment (876 versus 625 kg/ha, respectively, in 93 days).

Some tilapia reproduction occurred in all ponds as a result of a few misidentified females at stocking. An average of 34 fry/are were found in the all-tilapia ponds while only 10 fry/are were found in ponds containing *Clarias*. *Clarias* predation upon tilapia was confirmed by stomach analysis.

Stomach content analysis showed that *Clarias* fingerlings consumed 30% whole and broken rice from the rice bran, 30% vegetable matter from the compost and 19% insect larvae, by volume (Figure 3). The stomach contents of tilapia included 40% phytoplankton, 30% vegetable matter (primarily from rice bran and compost), and 10% zooplankton, by volume (Figure 4).

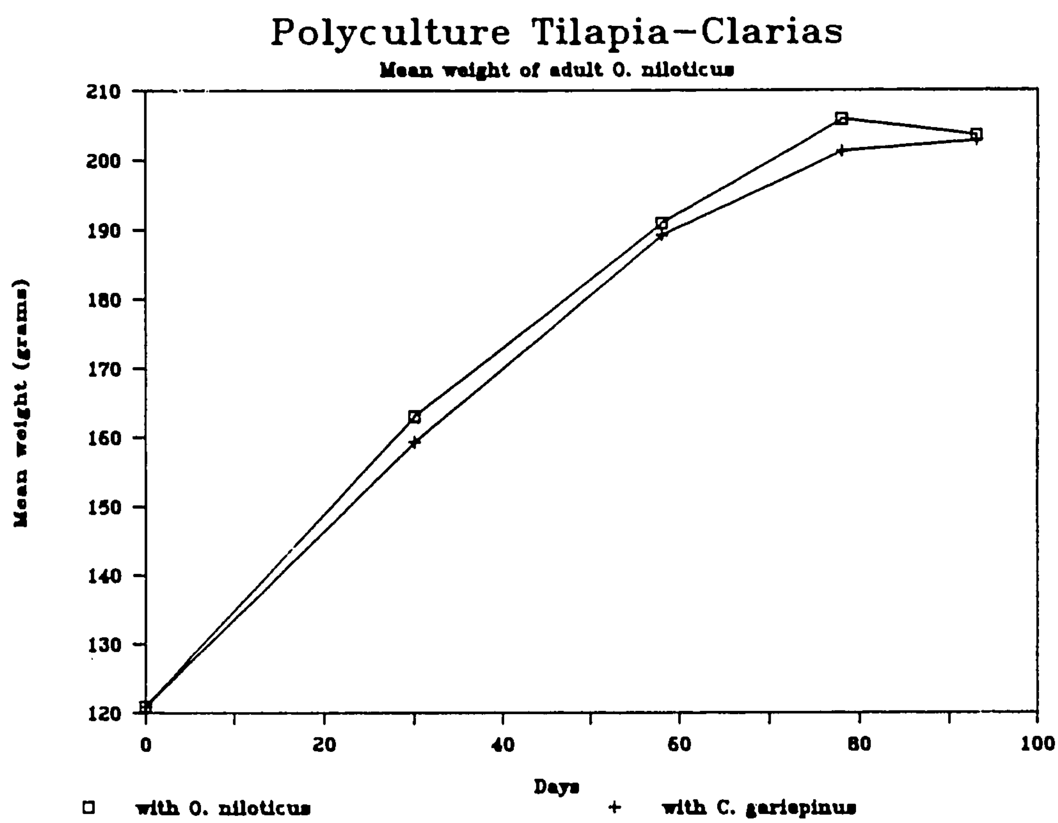

Figure 1. Mean weight of adult *Oreochromis niloticus* reared alone or with *Clarias gariepinus*.

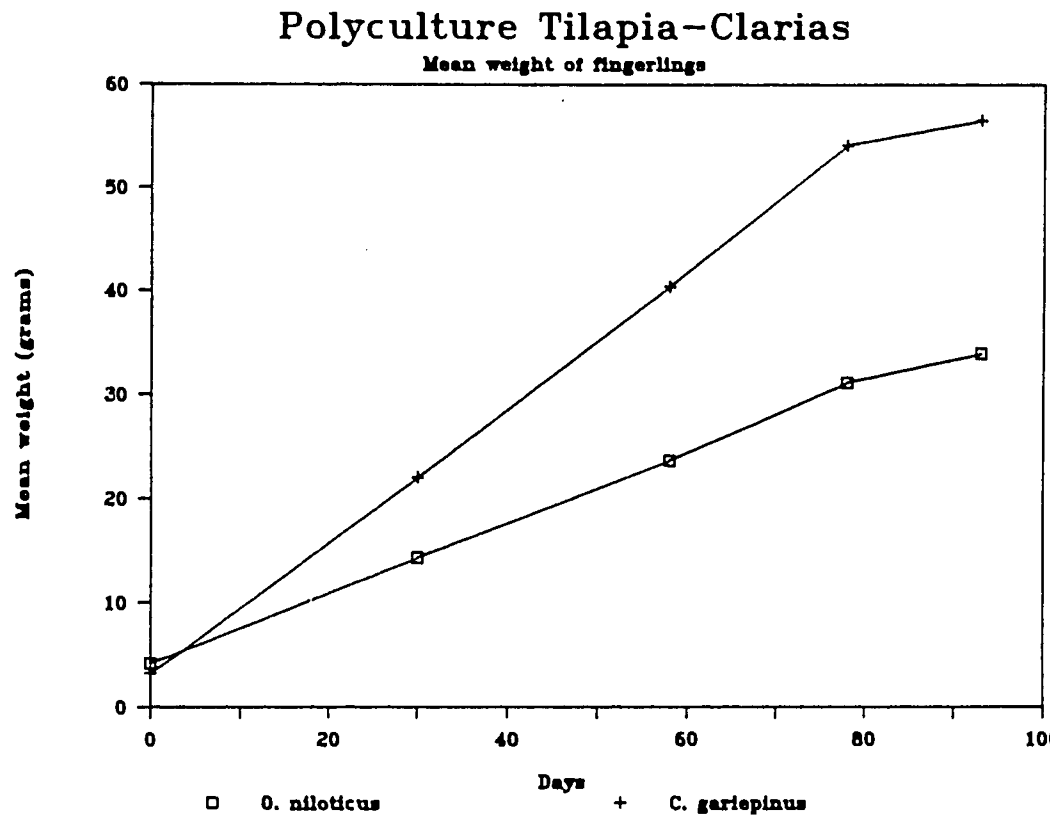

Figure 2. Mean weight of tilapia (*Oreochromis niloticus*) fingerlings in monoculture and of *Clarias* fingerlings in polyculture with tilapia.

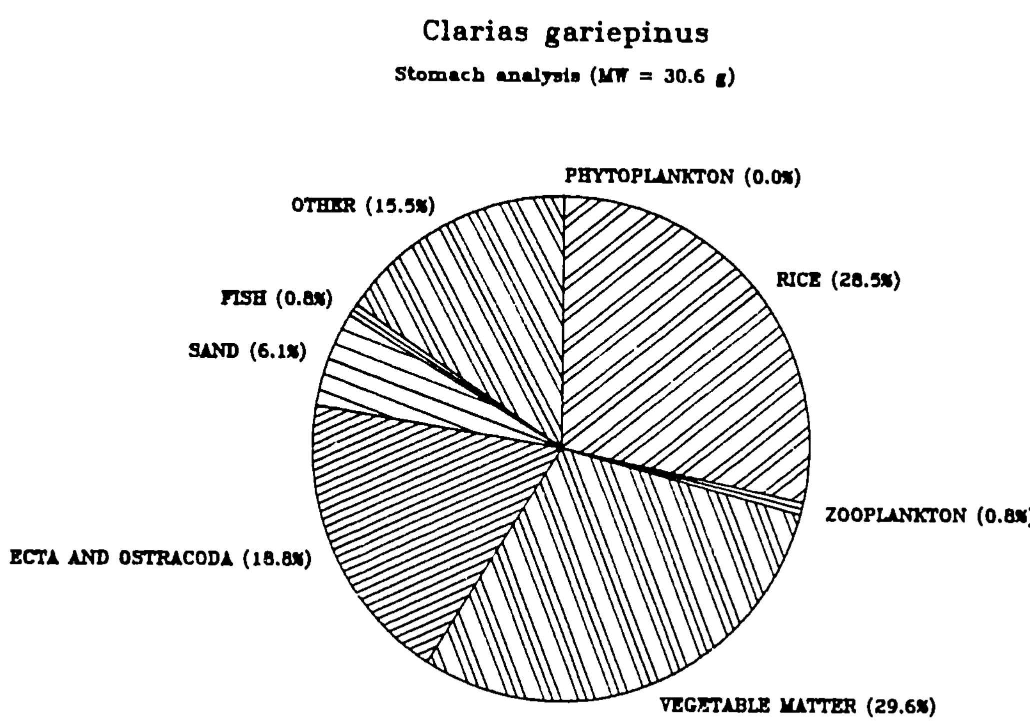

Figure 3. Stomach contents of *Clarias* fingerlings cultured with tilapia (*Oreochromis niloticus*).

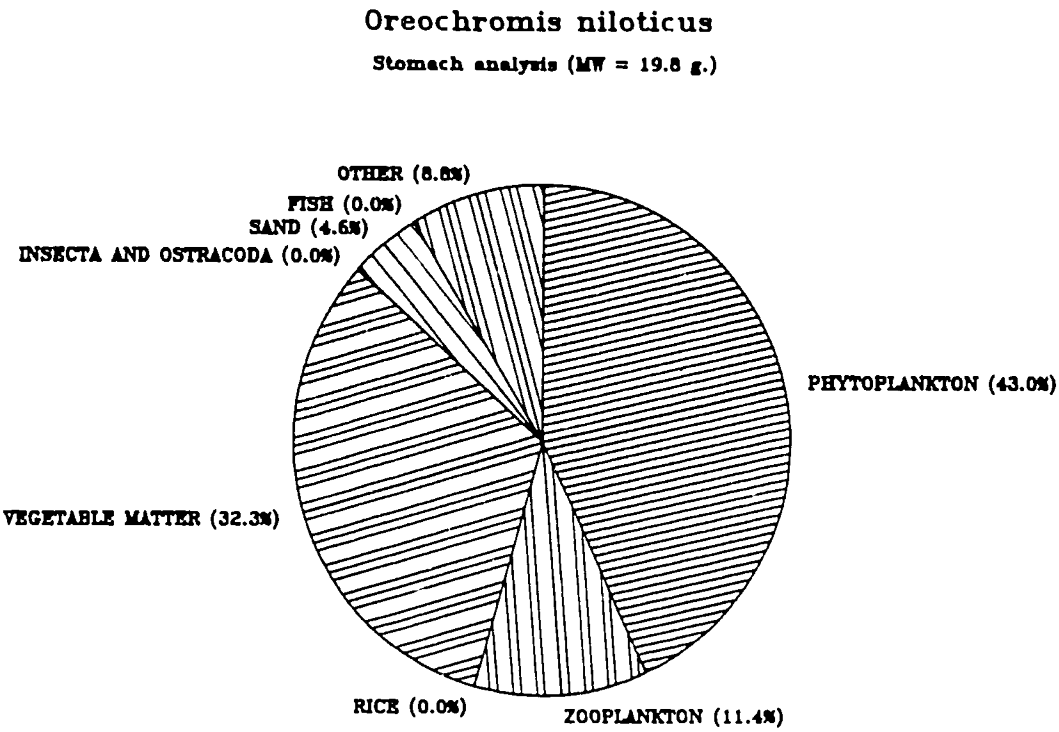

Figure 4. Stomach contents of tilapia (*Oreochromis niloticus*).

Anticipated benefits

The results of this experiment suggest the potential importance of *C. gariepinus* in Rwandan fish culture. Faster growth, different food habits, and apparent tolerance to poor water quality conditions are favorable characteristics of a species for polyculture with tilapia.

The Role of Sediments in Pond Fertility

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Abstract

Two experiments were conducted on the effects of sediments on pond fertility and fish production (Nile tilapia, *Oreochromis niloticus*). The first was a grow-out study which examined five types of bottom substrate. The five types of substrate (detritus-removed, detritus-accumulated, topsoil, deepsoil, and fishpond mud) were placed in 15 rectangular concrete tanks. The fishpond mud substrate gave the highest average chlorophyll *a* concentration (564 mg/m^3) during the last four weeks of the culture period. The chlorophyll *a* concentration was more constant in the detritus-removed treatment (16 to 401 mg/m^3) than in the fishpond mud treatment (16 to 1609 mg/m^3), which increased with time. Fish production was also highest in the fishpond mud treatment. The effect of sedimented organic matter as a direct feed for Nile

tilapia was indicated by 48.9% higher net production from the detritus-accumulated treatment than from the detritus-removed treatment (983 vs 660 kg/ha/d). The second experiment, which examined the accumulation and release of nutrients from pond sediments, was conducted in the laboratory. All soil types accumulated phosphorus, as indicated by increases in the phosphorus concentrations of topsoil, deepsoil, and fishpond mud. These concentrations were 0.01, 0.003, and 0.08%, respectively. All soil types acted as sources of nitrogen for the water column, as indicated by decreases in the nitrogen concentrations of the topsoil, deepsoil, and fishpond mud, which were equal to 0.04, 0.003, and 0.26%, respectively.

Abstract taken from M.S. Thesis, 47 p, Asian Institute of Technology.

Bias in Seine Sampling of Tilapia*

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Excerpt

Seine sampling is widely recognized by aquaculturists to produce upwardly-biased estimates of size. In conversation, this bias is sometimes mentioned as a reason for not including sampling data collected by seining when analyzing growth (i.e., only stocking and harvest data are used). Fisheries biologists recognize that many fish sampling methods produce biased size estimates and considerable effort is expended to correct for the bias (e.g., mesh selection curves) (Gulland 1983). Aquaculturists, on the other hand, tend to either ignore the bias or, worse, ignore the supposedly biased data.

This note quantifies the degree of bias in size estimates of Nile tilapia (*Oreochromis niloticus*) that were obtained from seine samples. It is based on a comparison of seine sample data collected the day before harvest and average fish size at harvest in a total of 92 ponds in Rwanda, Indonesia, Honduras, and Thailand (Table 1). Seine samples contained an average of 11% of the fish collected at harvest. Size estimates from the seine samples were an average of 7% ± 0.8% (mean ± standard error) greater than size measured at harvest (Figure 1). Based on this analysis, seine sampling has an upward bias of approximately 7% when estimating average fish size in an *O. niloticus* population. Whether or not this degree of bias is species-specific needs to be examined. It is suggested that size estimates of *O. niloticus* based on seine sampling be reduced by 7% if those data are to be combined with stocking and harvest data when calculating growth curves unless another conversion factor has been shown to be more appropriate.

**This paper will be published in its entirety as a NOTE in the Journal of the World Aquaculture Society.*

Table 1. Differences between weights estimated from seine samples and actual weights measured at harvest.

Country	Mean Difference	Standard Deviation	N	Standard Error
All	7%	7.8%	92	0.8%
Rwanda	8%	9.6%	28	1.8%
Indonesia	5%	7.1%	24	1.5%
Honduras	5%	3.7%	24	0.8%
Thailand	10%	8.5%	16	2.1%

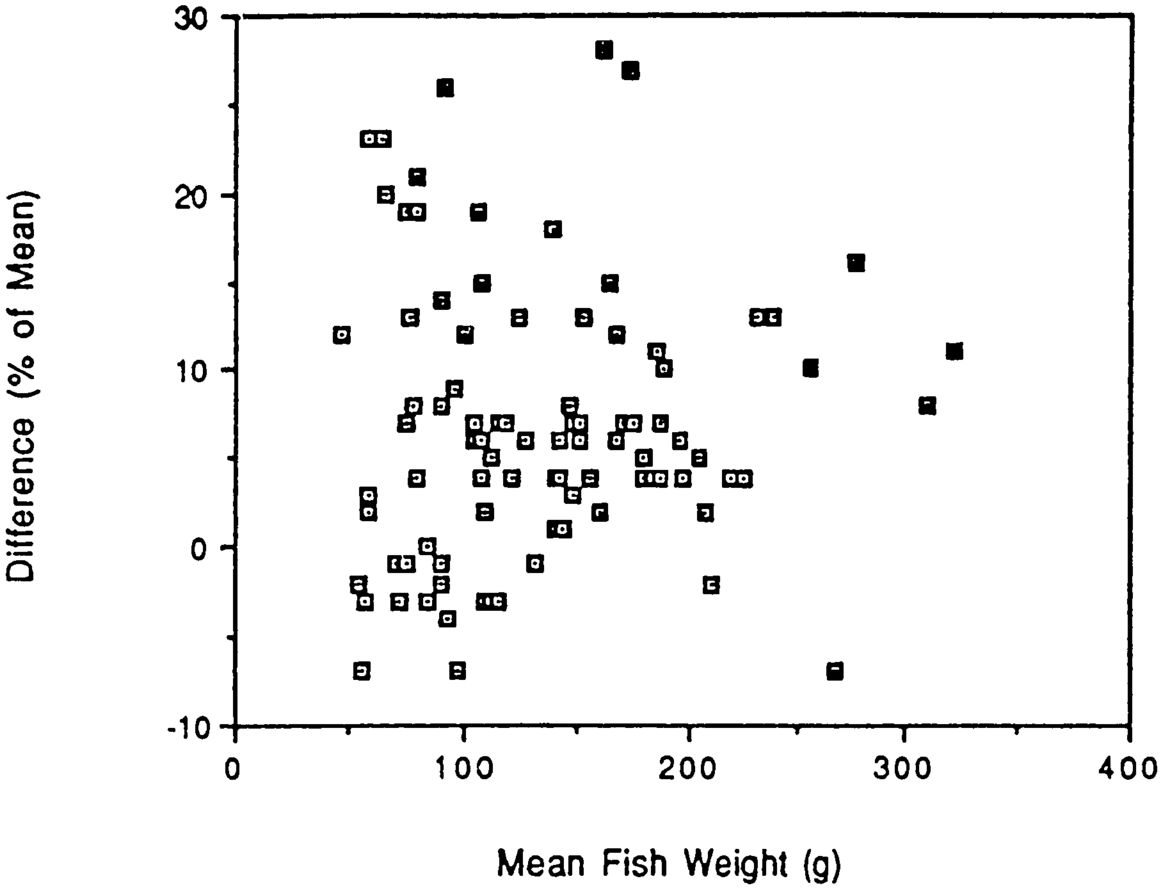
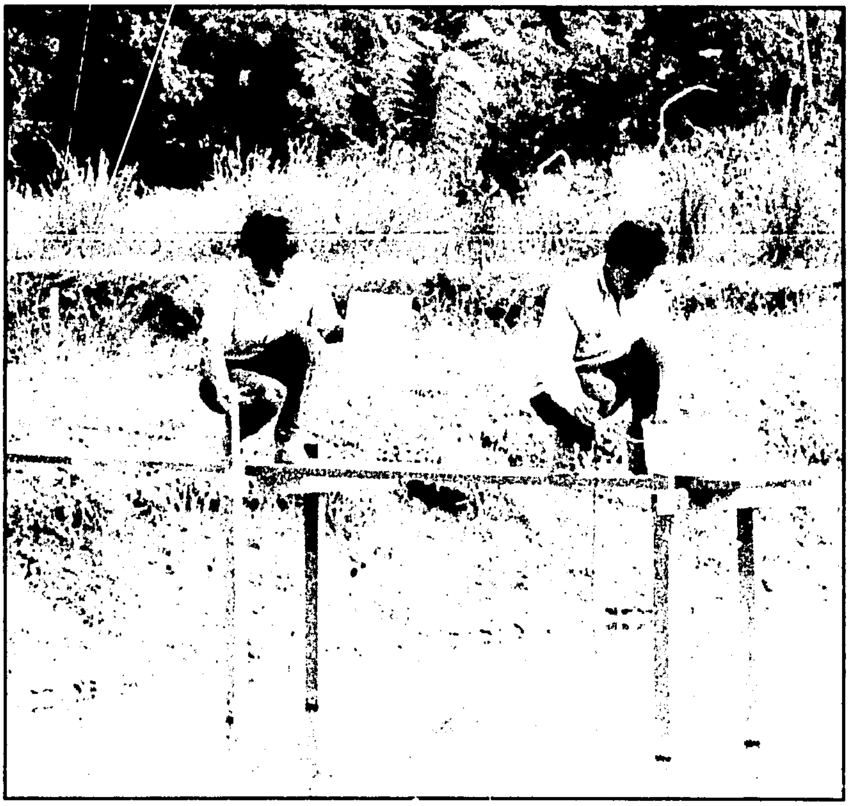


Figure 1. Difference between weights of tilapia estimated from seine samples and actual weights at harvest.



VII. Public Service and Project Development

Public Service

As Pond Dynamics/Aquaculture CRSP projects in developing countries become integrated into USAID's "country strategy," opportunities for providing support to scientific research institutions for training and for extending CRSP research results to the people of these countries have arisen. In each country project of the CRSP, researchers have recognized these opportunities and have assisted their counterparts in initiating appropriate activities. Although ancillary to the Global Experiment and site-specific studies, these activities contribute to institution building and increased food production, thereby furthering the main strategic approach. These activities also help to promote international scientific linkages through the exchange of technical information. As a result of these contributions, research capabilities have been substantially strengthened and private fish farming operations have been assisted in every developing country in which the CRSP has been active. Some of these important contributions are described below.

Institution Building

The Rwasave Station has been given departmental status as a research station by the National University of Rwanda (UNR), the first university research station to be so recognized. The station is beginni to attract funding from outside sources, including the Catholic University of Leuven, Belgium (CUL), which will collaborate on *Clarias* fingerling production research. The CRSP was honored by an offer from President Juvenal Habyarimana of Rwanda to lend the use of two of his personal ponds for on-farm trials. A multi-purpose room and wet lab were constructed this year at the Rwasave station. Six inside and four outside holding tanks were built, and additional lab space is now available in the multi-purpose room. The holding tank room can house 10 to 20 aquaria. In Honduras, ponds were renovated during the summer in preparation for a new cycle of experiments.

CRSP scientists working in each country served as advisors in the research programs of students at host-country universities and made contributions to curriculum development. Chris Knud-Hansen introduced research methods into the curriculum at the Asian Institute of Technology in Thailand (AIT) by teaching a course entitled *Experimental Design and Analysis in Aquaculture*. Knud-Hansen also served as the principal instructor for the short course, *Experimental Design, Biostatistics, and Computer-Based Data Analysis*, held for IDRC fish health workers at the School of Biological Sciences, Universiti Sains Malaysia, in Penang, Malaysia. Kevin Hopkins presented a seminar on fish growth to students enrolled in an AIT graduate course in fish bioenergetics.

Karen Veverica, the US field scientist in Rwanda, taught short courses at UNR in introductory ecology, fisheries, introductory fish culture, and biological productivity. She also gave a one-day short course on aquaculture to farmers from area communes. The CRSP experimental facility in Rwanda continued to be of interest as a destination for student field trips. Primary, secondary, and university students, as well as trainees from the teachers' training center, visited the station to learn about biology of fish, fish culture techniques appropriate for Rwanda, and the recycling of farm by-products. The station also continued to be a resource to fish culture extension agents, who meet with CRSP researchers for advice and planning. David Teichert-Coddington, Ivan Rodriguez, and Luis Lopez taught a two day intensive course in aquaculture to seniors at the J.F.K. Agricultural School in La Ceiba, Honduras. Nathan Stone, UAPB, taught a pond construction short course to RENARE aquaculture personnel.

A handbook of analytical methods used in the CRSP is being prepared by the Technical Committee. This new handbook will include detailed methods from standard reference manuals or other relevant sources, and will replace the materials and methods section currently included in the Work Plans. Its loose-leaf format will allow easy updating as methods are changed, added or deleted. This effort may be the starting point for the production of a comprehensive manual of aquaculture methods for distribution to researchers outside the CRSP.

Training

Although training is not formally a component of this CRSP, the involvement of students from host countries and the United States constitutes an important part of the CRSP's international outreach. Informal training activities such as short courses and workshops are frequently conducted at the CRSP research sites or at other overseas locations (both in host countries and regionally) by CRSP researchers. Over 350 individuals have benefited from informal training activities since the beginning of the program; at least 250 individuals received training during this reporting period. Thirty-six Rwandan farmers, including the foreman of President Habyarimana's farm, were trained in techniques of applying inorganic fertilizer and in using standardized methods for cutting and weighing grasses to be used in the on-farm trials. Many additional individuals are known to have benefited through similar contacts with CRSP activities and scientists, even though their numbers were not recorded.

Enthusiasm generated by such informal training and by exposure to activities at the CRSP research sites has led some students to pursue university degree programs, either at institutions in their own countries or at participating U.S. universities. Students have pursued degrees in at least seven overseas institutions and at all of the collaborating universities in the U.S. (Table 1). Prior to this reporting period at least 85 degrees (B.S., M.S., and Ph.D.) were awarded, and during this period another 10 were completed (Table 2). The following theses were completed under the direction of CRSP researchers during this period:

- Boonsong, S. 1990. Role of zooplankton in feeding juvenile tilapia (*Oreochromis niloticus*). M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.
- Gatera, Anaclet. 1990. Effect of stocking rate and composting regime on production of fish in ponds. Universite National du Rwanda, Butare, Rwanda.
- Jiwyam, Wirat. 1990. The role of sediments in pond fertility. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand. 47 pp.
- Mukakarera, Colette. 1990. An aquatic biology study of Uwagatigita and Mbirurume streams in the Nyungwe natural forest. Universite National du Rwanda, Butare, Rwanda. 101 pp.
- Munyangaju, Aloys. 1990. A study of the lakes in the Bugesera region for the purpose of developing an optimal fishing effort. Universite National du Rwanda, Butare, Rwanda. 102 pp.
- Narong V. Effects of phytoplankton on nursing walking catfish fry in static and flow-through water systems. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.
- Niyitegeka, Domitille. 1990. Nitrogen budgets in fish ponds enriched with fertilizers of different C:N:P ratios at Rwasave, Butare. Universite National du Rwanda, Butare, Rwanda. 117 pp.
- Rwalinda, Pierre. 1990. Enrichment of compost with nitrogen and phosphorus and its effects on the production of *Tilapia nilotica*. Universite National du Rwanda, Butare, Rwanda. 117 pp.
- Rwangano, Felicien. 1990. Interactions of input types and water quality on the production of *Oreochromis niloticus* (L.) in Rwandan ponds. M.S. Thesis, Oregon State University, Corvallis, Oregon. 99 pp.
- Suresh, A.V. 1990. Influence of stocking density on red tilapia production in a recirculation system. M.S. Thesis, Asian Institute of Technology, Bangkok, Thailand.

The number of individuals involved in all forms of training, from non-degree activities through work on advanced degrees, has climbed to well over 400 since the beginning of the program. Most of the trainees have come from PD/A CRSP host countries (Panama, Philippines, Indonesia, Honduras, Thailand, and Rwanda); however, the benefits of CRSP-related training have extended well beyond the borders of the six collaborating countries, as evidenced by the fact that participants have been drawn from at least 25 countries over the course of the program. Although many participants may not remain directly involved in aquacultural work, the experience they have gained with the CRSP allows them to contribute to awareness and interest in the wider community, as they take up positions in schools, banks, agricultural research institutes, national parks services, development projects, and agricultural extension services in their respective countries.

TABLE 1. List of Participating Institutions

Asian Institute of Technology (Thailand)
Agricultural University of Bogor (Indonesia)
Auburn University
Catholic University of Chile
Kasetsart University (Thailand)
Michigan State University
National Autonomous University of Honduras
National University of Rwanda
Oregon State University
University of Arkansas at Pine Bluff
The University of California at Davis
The University of Hawaii
The University of Michigan
University of Panama
University of the Philippines in the Visayas

TABLE 2. Degrees Awarded for CRSP-Related Studies

	B.S.	M.S.	Ph.D.	Total
Before 1989	53	22	10	85
1989-1990	5	5	0	10
Total	58	27	10	95

Linkages

The CRSP continues to establish and maintain important linkages with other organizations involved in aquacultural and agricultural research and development. Michigan State University (MSU) continues to serve as the North Central Regional Aquaculture Center (NCRAC) under a grant from the U.S. Department of Agriculture Cooperative State Research Service. MSU was identified as the lead university for the NCRAC largely because of its long-standing involvement in the PD/A CRSP.

Members of the Data Synthesis and Analysis Team (DAST) at the University of California, Davis (UCD), continued a joint project with the University of Hawaii's Mariculture Research and Training Center and the Hawaii Institute of Marine Biology to evaluate data collected from Hawaiian research ponds using CRSP models. Such collaborative work not only provides additional data for validating CRSP models, but also extends the usefulness and applicability of CRSP models and research efforts.

The CRSP maintains close ties with the International Center for Aquaculture (ICA), in Auburn, Alabama through Auburn University's involvement in the CRSP. The CRSP is also working with the International Center for Living Aquatic Resources Management (ICLARM) on the development of a handbook of aquacultural research techniques. This handbook is an outgrowth of the CRSP work plans, and addresses a need identified by CRSP scientists in the early stages of the program— to establish standardized techniques for use in aquacultural research worldwide. The outline and one chapter of the manual were completed this year.

In Honduras, researchers served as consultants for Peace Corps volunteers on the formation of a computerized data base for recording and evaluating Peace Corps aquacultural activities in Honduras. The CRSP plans to contribute technical advisors to Peace Corps; in turn, the Peace Corps may assist with the field testing of CRSP pond management techniques. In addition to the organizations specifically mentioned above, the CRSP maintains ties with numerous other organizations. These include:

Board for International Food and Agricultural Development (BIFAD), Washington, D.C.
CARE, Honduras
Catholic University of Leuven (CUL), Belgium, Rwanda
Central Luzon State University, Philippines
Consultative Group on International Agricultural Research (CGIAR), Washington , D.C.
Department of Aquaculture (DINAAC), Panama
Food and Agriculture Organization of the United Nations (FAO), Rome, Italy
Freshwater Aquaculture Center (FAC), Philippines
Gondol Research Station, Ensenada, Mexico
Institut Pertanian Bogor (IPB), Indonesia
International Development Research Centre (IDRC) of Canada, Malaysia
International Rice Research Institute (IRRI), Philippines
International Center for Aquaculture (ICA), Auburn University, Alabama
J.F.K. Agricultural School, Honduras
National Aquacultural Library, Washington, D.C.
National Inland Fisheries Institute (NIFI), Thailand
National Marine Fisheries Service (NMFS), Seattle, Washington
Peace Corps, Honduras and Thailand
Department of Renewable Natural Resources (RENARE), Honduras
Special Program for African Agricultural Research (SPAAR), Washington, D.C.
The University of the Philippines in the Visayas
Western Regional Aquaculture Consortium (WRAC), Seattle, Washington
Zamorano, Honduras

Project Development

New Areas of Emphasis for the CRSP

Sensitivity toward the environment and appreciation of the need for sustainable agriculture have always been characteristic of the PD/A CRSP. Worldwide attention is now beginning to focus on sustainable development to meet the needs of the present without compromising the ability of future generations to meet their own needs. This year, the CRSP helped in natural resource policy development and implementation at several sites. A corollary to successful sustainable agriculture is a strong Women in Development component, because improving women's economic status eases population pressure. The CRSP has taken a more active role in encouraging women in aquaculture. Transfer of successful and appropriate technology continues to take place, as the private sector capitalizes on the CRSP research. These payoffs take place not only in the Host Countries, but also in the United States. The models and guidelines developed by CRSP researchers are being used in directing on-farm trials, the "acid-test" of new techniques and technologies. The CRSP approach recognizes that new technology does not operate in a vacuum; socioeconomic studies to analyze optimal resource use continue to be part of the research plan.

Natural Resource Policy

As environmental concerns move us toward more sustainable agricultural systems worldwide, aquacultural production will continue to fill an important niche. Pond production of animals and plants is an important component of integrated agricultural systems in several ways. Aquaculture ponds provide an efficient means of conserving water in areas where water supplies are limited. Further, effluent from ponds need not be dumped directly into natural waterways, but can be used for irrigation. Pond mud– often high in organic matter and rich in nutrients– can be partially removed and used as a fertile soil additive for land crops. Other examples of the integration of pond aquaculture with other forms of agricultural production include such combinations as pig-fish, chicken-fish, and duck-fish operations, and the use of farm by-products such as manures, grasses, inedible plant parts, and composts as nutrient sources in ponds. CRSP research at all sites continues to emphasize the development of efficient ways of utilizing these agricultural by-products to enhance production in ponds, and to contribute to sustainability by recycling farm materials.

Thirty participants from a seminar on environmental planning, representing half a dozen African nations, toured the Rwasave Fish Station, which was cited as a station with exemplary environmental sensitivity. The method for controlling fish loss to pelicans is a good example of the environmentally sound, appropriate technology for which the Rwasave Station is becoming known. Inexpensive twine is strung in a grid pattern close to the surface of the pond, thus discouraging pelican predation. Karen Veverica, the CRSP Research Associate, provided substantial advising for an Environmental Impact Assessment of Aquaculture Development in Rwanda. The study was required for implementation of the USAID-funded Natural Resources Management Project, and was jointly funded by the USAID Mission in Kigali and Auburn University's Program Support Grant. Collaborative planning for research in integrated agriculture-fish culture systems was undertaken with Belgian researchers and with the International Development Research Centre (IDRC). This integrated approach to food production was emphasized in the *New York Times* article "Why Worry About Crops When Fishing's Better!" (December 14, 1989), which pointed out how farmers are able to increase their fish yields by up to 600% by using animal and vegetable waste.

CRSP experiments in Honduras addressed water quality issues, which are of concern not only in ponds during the production cycle, but also as effluents leave ponds and are returned to the larger ecosystem. Other experiments in Honduras and Thailand were run to determine the most efficient level of nutrient inputs. The results of this study allow farmers to manage fertilizer use to ensure optimal fish production without pollution. CRSP scientists at all sites share a concern for the wider environment and the effects of aquacultural production on it. Environmental concerns must continue to be given highest priority in all countries, whether temperate or tropical, lesser-developed or highly developed, as researchers attempt to find improved techniques for meeting the nutritional needs of a rapidly growing world population.

CRSP scientists also are involved in researc' ;ared toward increasing food production using indigenous fish species. For example, work in Thailand has studied environmentally-induced ovarian development and hatchery techniques for fry production of the walking catfish, *Clarius batrachus*. Species such as *C. batrachus* are suitable for aquaculture and can contribute greatly to overall food production because they are already well-known, desired food fish and because they are hardy. This hardiness makes it possible for farmers to stock and grow them at relatively high densities or in oxygen-poor water; it also means that the fish can be marketed *live*, an important factor to consumers in many regions. Using indigenous species wherever possible reduces potential risks to ecosystems which may result from the indiscriminate use of exotic species.

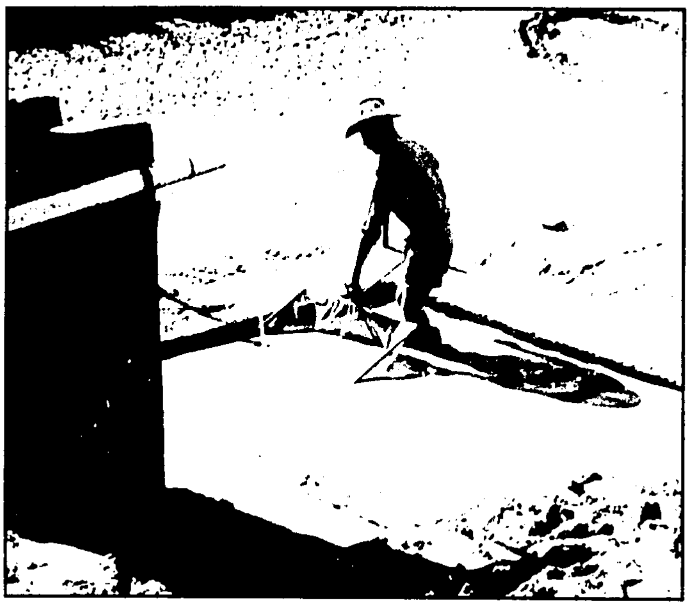
Women in Development

Women's involvement in aquaculture can have profound effects on the environment and the economy of a country. With population pressure the main threat to the environment, it is imperative that women feel secure in having fewer children whose chances for survival are good. Improved nutrition from fish can provide that security. A first step in involving women in aquaculture is to provide training. At least 39 women from eleven countries have been involved in CRSP-related training or other educational activities since the inception of the program. Women account for more than 25% of all training that has occurred because of the CRSP's existence. To date, twenty-eight women have received training at overseas locations, and eleven have studied at U.S. institutions. Training has included 17 non-degree activities (short courses, etc.), and 26 degree-related efforts (19 B.S., 4 M.S., and 3 Ph.D. degrees). Thirty percent of the theses completed this year under the direction of CRSP researchers were written by women. Nearly half the graduate students involved in CRSP research are women.

In Rwanda, one quarter of fish farmers today are women. They are benefiting from CRSP research on integrated fish farming, which uses low-cost agricultural waste to enhance pond productivity. A proposal has been submitted to the Food and Agriculture Organization of the United Nations (FAO), the Program Support Grant at Oregon State University, USAID/Washington, and the USAID Mission in Kigali to document and extend the success of this project to other sites. The study also would explore ways of increasing extension support to include post-harvest issues, and would analyze the impact that the adoption of fish farming has on household nutritional status and economic well being.

Private Sector Involvement

The Rwasave Fish Culture Research Station in Rwanda has become almost self-supporting, using funds generated from the sale of fish, pork, produce, and water quality laboratory services. The laboratory now regularly contracts for soil and water analyses, and is becoming a major analytical center for newly implemented sewage treatment plants. CRSP researchers also advise private and communal farms on integrated fish farming, and collaborate with private farmers in conducting on-farm trials of techniques developed at the CRSP research site.



CRSP research findings do not benefit only Host Country producers; research proving the efficacy of sustainable inputs such as green grass and compost will have immediate application in California, Arizona, and Idaho, where fish farmers are investing heavily in tilapia ventures, and in other Less Developed Countries (LDC) as results are published in scientific journals and shared with other scientists at international meetings and conferences. The issues of water quality and water conservation addressed by CRSP research will be critical in developing aquaculture in water-deficient areas in both the U.S. and abroad. Tilapia, the key species used in CRSP experiments, also has marketing potential in the U.S. As U.S. demand for fish soars, aquaculture expansion will probably become pronounced in the South and Southeast, where farmers searching for new cash crops are expected to convert more agricultural land to aquacultural production.

Socioeconomic Studies

Carole Engle completed the CRSP's first comprehensive economic study in Rwanda. The study characterized resource availability, quantified resources used, and estimated the benefits of aquaculture to the farmer. Sixty farmers (30 each in low- and high-altitude regions of the country) were interviewed

to obtain data on labor requirements for various fish production activities, market channels, fish prices, other crops and livestock raised, equipment owned and types of inputs utilized in fish farming. Data on pond construction, stocking, fertilization, feeding, and harvesting were recorded from pond records maintained by extension agents. These data were analyzed to compare labor efficiency and costs and returns for aquaculture in low- and high-altitude regions. Results showed that production was higher in low-altitude ponds, but output per person-day of labor was the same as in high-altitude ponds. Another important finding was that the value of fish produced exceeded the costs of the labor invested in production, verifying the economic efficiency of fish farming. In Thailand, considerable effort has been devoted to compiling cost and return information to supplement the technical data collected during the CRSP experiments. This information will be used to conduct economic studies of existing aquaculture operations, and will also be useful in the Thailand studies funded by the Bean/Cowpea CRSP in December 1990.

Participation in International Scientific Meetings and Conferences

CRSP scientists continue to maintain contact with the wider aquaculture community and share the results of their research through participation in scientific meetings and conferences.

- Five CRSP participants attended the annual meeting of the World Aquaculture Society held in Halifax, Nova Scotia, Canada, in June 1990. William Chang, Raul Piedrahita, Bob Springborn, and James Szyper presented papers based on CRSP research. Bob Fridley presented the preliminary report assessing technology and opportunities for Marine Aquaculture in the United States.

- David Teichert-Coddington and Bart Green presented papers and posters at the Symposium on Production Enhancement in Still Water Pond Fish Culture in Prague, Czechoslovakia, sponsored by the European Inland Fisheries Advisory Commission.

- C. Kwei Lin attended the Third Asian Fisheries Forum in Singapore.

- Philip Giovannini, of the Data Analysis and Synthesis Team (DAST), presented the paper "Measuring primary production efficiency in aquacultural ponds" at the June meeting of the American Society of Agricultural Engineers in Columbus, Ohio. In January 1990, he chaired two technical sessions and presented two papers at the society's meeting in New Orleans.

- Raul Piedrahita participated in a workshop on milkfish fry production at Gondol Research Station in Bali, Indonesia. He also presented a lecture on Aquacultural Engineering at the Universidad de Baja California in Ensenada, Mexico.

VIII. Program Management and Technical Guidance

The basic organizational structure of the Pond Dynamics/Aquaculture CRSP remained the same as in previous years, although new appointments were made to the Management Entity and the Technical Committee.

Management Entity

Oregon State University continued to function as the Management Entity for the Pond Dynamics/Aquaculture CRSP. The Management Entity moved to the Office of International Research and Development (OIRD) in the summer of 1986 from its original home in Newport, where it had been based since 1982. This location, which is next to the Oregon State University Administration Building, facilitates the streamlining of many administrative details essential in properly administering the CRSP Grant. The CRSP also is part of OSU International Fisheries at OIRD, which comprises the Consortium for International Fisheries and Aquaculture Development (CIFAD), the Foreign Fisheries Observer Program, and the International Institute of Fisheries Economics and Trade. This arrangement with OIRD affords the Management Entity increased support in accounting, purchasing, and other services. The Management Entity is fully integrated into the larger framework of international agricultural programs at Oregon State University and derives benefits from interacting with these programs. The CRSP, formerly part of the Department of Fisheries and Wildlife in the College of Agriculture, now reports directly to the Vice President for Research, Graduate Studies, and International Programs through the Director of OIRD. Ties to the Department of Fisheries and Wildlife, however, are maintained through faculty appointments and academic interests.

The Program Management Office provides executive linkage between the Management Entity and operations under the CRSP. During this reporting period, members of the Program Management Office included:

- Dr. Howard H. Horton, Director (0.55 FTE) through December 1989
- Ms. Hillary S. Egna, Associate Director (1.0 FTE) through December 1989; Acting Director (1.0 FTE) through June 1990; Director (1.0 FTE) from July 1990
- Ms. Hilary Berkman, Data Base Manager (0.4 FTE)
- Mrs. Lydia Perry, Secretary (0.5 FTE) through 30 December 1989
- Ms. Marion McNamara, Secretary (0.5 FTE) December 1989 through July 1990; Assistant Director (1.0 FTE) from August 1990

The Management Entity (ME) is responsible for:

- Receiving funds committed by USAID to the CRSP and assuming accountability for their use;
- Providing funds to the participating institutions, and ensuring compliance with terms of the Grant;
- Providing a focal point for the interaction of the Technical Committee, Board of Directors, External Evaluation Panel, USAID staff, and BIFAD/JCARD;
- Executing the decisions of the governing and advisory bodies;
- Implementing the program; and
- Maintaining liaisons with overseas and domestic participants.

The ME also is responsible for communications, publications, and management of the CRSP Central Data Base.

Specific accomplishments include:

- Modification of the five-year continuation plan, which was reviewed in May and September 1989 by BIFAD, JCARD, and accepted by AID as the new CRSP grant document for 1990-1995;
- Preparation of CRSP budgets and subcontractual modifications for extending funding and performance periods;
- Negotiation and implementation of new CRSP grant, including preparation of new budgets and subcontracts;
- Coordination and preparation of a proposal for collaborative research in aquaculture with Egypt under the National Agricultural Research Project (NARP);
- Site visit to the Rwasave Fish Culture Center and Universite du Rwanda;
- Continued assistance in processing travel clearances for CRSP personnel and approvals for purchases of restricted goods for country projects;
- Continuation of a technical information service for overseas research staff whereby abstracts and tables of contents of current journals are sent to U.S. Research Associates as requested;
- Publication of research results in two technical report series, including three data reports;
- Organization of the eighth annual CRSP meeting in East Lansing, Michigan on May 21-23, 1990 and participation in attendant Board Meetings and Technical Committee meetings;
- Coordination and publication of the Fifth Work Plan;
- Compilation of the standardized data sets from the three work plans (experimental cycles) completed at seven overseas locations;
- Coordination of activities for the CRSP Data Analysis and Synthesis Team, the principal U.S.-based research component of the CRSP;
- Coordination of development of a peer evaluation process to be used within the CRSP;
- Development of questionnaires to evaluate the Annual and Technical Committee meetings, and to coordinate meeting logistics to better enable host country participants to attend;

- Maintenance of the directory which lists CRSP participants' electronic mail codes (e.g., FAX. BITNET, TELEX, MCI);
- Participation in Board Meetings and Technical Committee meetings;
- Assistance to S&T/AGR through participation on CRSP Council;
- Participation in CRSP Council presentations to Congress, the World Bank, USAID, and environmental groups, 7-9 February 1990;
- Coordination of new administrative and contractual details for collaborative research projects in Thailand, Rwanda, and Honduras;
- Maintenance of the CRSP mailing list, which reaches over three hundred people in 35 countries;
- Attendance at the Consultative Group on International Agricultural Research (CGIAR)-sponsored International Centers Week, 30 October -3 November 1989;
- Participation in the CIFRAI meeting, 27 September 1990
- Participation with other CRSP directors in Bean/Cowpea CRSP Annual Meeting, May 1990.

Technical Committee

Technical guidance is provided by a Technical Committee composed of the Principal Investigators of CRSP Research Projects and at-large members appointed by the Board of Directors. The Technical Committee has four standing subcommittees: Work Plans, Materials and Methods, Budgets, and Technical Progress. The membership of the Technical Committee and subcommittees is presented in Table 3.

Table 3. Technical Committee Assignments

Name	Institution	Subcommittees[1]
Principal Investigators (Voting Members)		
Ted Batterson	Michigan State University	B*
Jim Diana	University of Michigan	T
Peter Edwards	Asian Institute of Technology, Thailand	W
Carole Engle	University of Arkansas at Pine Bluff	W
Bart Green	Auburn University	W
Kevin Hopkins	University of Hawaii	W*
Evariste Karangwa	University of Rwanda	W
Jim Lannan	Oregon State University	T*
Raul Piedrahita	University of California, Davis	M*
Tom Popma	Auburn University	W
Ivan Rodriguez	Directorate of Renewable Natural Resources	B
Wayne Seim	Oregon State University	B
Jim Szyper	University of Hawaii	M
Non-Voting Members		
Hilary Berkman	Oregon State University, Management Entity	
Claude Boyd	Auburn University	M
Bryan Duncan	Auburn University	T§
Sompong Hiranyawat	National Inland Fisheries Institute, Thailand	
Howard Horton (to Dec '89)	Oregon State University, Management Entity	
Chris Knud-Hansen	Michigan State University	
Kwei Lin	University of Michigan and AIT, Thailand	
Cal McNabb	Michigan State University	
Eugene Rurangwa	National University of Rwanda	
David Teichert-Coddington	Auburn University	
Richard Tubb	Oregon State University	T§
Sompote Ukkatawewat	National Inland Fisheries Institute, Thailand	
Karen Veverica	Auburn University and Oregon State University	
At-large-Members		
Dr. Donald Garling	Michigan State University	
Dr. George Tchobanoglous	University of California at Davis	
Ex-officio Members		
Hillary Egna	Oregon State University, Management Entity	
Chris Jones	S&T/AGR, U.S. Agency for International Development	

[1] W=Work Plans; B=Budgets; T=Technical Progress; M=Materials and Methods

*Subcommittee Chairpersons § Temporary subcommittee assignments

Board of Directors

As the primary policy-making body for the CRSP, the Board of Directors takes an active role in program guidance. The Board is composed of three members, one of whom is elected chairman. Each of the participatory institutions is represented on the Board. The Program Manager from USAID and the CRSP Director serve as ex-officio members. All Board members function in the objective interest of the CRSP regardless of their institutional affiliation. During this reporting period, the Board members were:

- Dr. Robert Fridley, University of California at Davis, Member;
- Dr. Philip Helfrich, University of Hawaii (CIFAD institution), Member and Chairman;
- Dr. R. Oneal Smitherman, Auburn University, Member;
- Mr. Chris Jones, NMFS, IPA to S&T/AGR , Ex-Officio Member;
- Dr. Howard Horton, Oregon State University, CRSP Director to December 1989, Ex-Officio Member;
- Ms. Hillary Egna, Oregon State University, CRSP Acting Director from January 1990 to July 1990, Director from July 1990, Ex-Officio Member.

The Board of Directors convened four times during this reporting period.

- November 8, 1989 Telephone Conference Call
- May 4, 1990 Telephone Conference Call
- May 20 and 21, 1990 East Lansing, Michigan

The Board of Directors is responsible for:

- Review of program budgets and allocation of funds to research projects and the Management Office;
- Recommendations to the Management Entity on budget allocations;
- Evaluation of the administrative and technical accomplishments of overseas research projects and U.S.-based research activities;
- Advice to the Management Entity on policy guidelines; and
- Review of the performance of the Program Director and Management Entity.

Specific accomplishments and recommendations made during this reporting period include:

- Review of progress of Data Base Management and the Data Analysis and Synthesis Team;
- Approval of management and research budgets;
- Appointment of a new CRSP Director;
- Review of the research proposal for Egypt;
- Annual meeting agenda input and approval;
- Advice on international travel procedures;
- Guidance on efforts to strengthen the program in the face of funding constraints; and
- Participation in the eighth annual program meeting in May 1990.

External Evaluation Panel

The External Evaluation Panel is composed of impartial senior aquaculture scientists who were selected on a worldwide basis. The three members of the Panel represent the major disciplines of the CRSP. All have considerable international experience in aquatic sciences. During this reporting period, the members of the External Evaluation Panel were:

- Dr. Homer Buck, Illinois Natural History Survey
- Dr. Kenneth Chew, University of Washington, Seattle, Washington
- Dr. Herminio Rabanal, Aquaculture Consultant, The Philippines

The External Evaluation Panel (EEP) reviewed the technical plan for continuation of the Global Experiment from 1990 to 1995. The EEP review provided guidance for the Triennial Review conducted by the JCARD CRSP panel and USAID's Agriculture Sector Council Subcommittee. The results and recommendations of this review were included in the Continuation Plan submitted to JCARD, BIFAD, and AID in September 1989. Dr. Homer Buck attended the eighth annual meeting in East Lansing in May 1990.

CRSP Publications

The CRSP facilitates technology dissemination through its various publications. These publications reach a broad domestic and international audience. During this reporting period, the number of publications resulting from CRSP research continued to grow. Over 330 reports and theses have resulted from CRSP research worldwide.

Over 300 people in more than 35 countries now receive our publications. The two publication series that were launched in 1987 have attracted many new readers. These two publications highlight CRSP research on a variety of subjects related to aquaculture. *CRSP Research Reports* contains scientific papers written by CRSP researchers. The goal of *CRSP Research Reports* is to publish all research produced by CRSP activities, with the exception of research related directly to the Global Experiment. For this purpose, *Collaborative Research Data Reports* was created.

Collaborative Research Data Reports contains the results and data from the Global Experiment, which is the major research activity of the CRSP. *Collaborative Research Data Reports* presents the CRSP Central Data Base along with interpretations of site-specific results. The first volume of *Collaborative Research Data Reports* is a reference for the series; it contains descriptions of sites and experimental protocols for the Global Experiment. Subsequent volumes focus on each research site separately by experimental cycle. The rate of output of both *Collaborative Research Data Reports* and *CRSP Research Reports* has accelerated as a result of recent improvements in the Central Data Base.

These two publications add to the informational base that the CRSP has established over seven years. *Aquanews*, the program's newsletter, contains informative articles on field projects, summaries of training courses and meetings about aquaculture, and brief notes on the program and its participants. *Aquanews* provides a forum for host country and U.S. participants to share ideas and preliminary research findings.

Other reports published by the CRSP Program Management Office include Annual Administrative Reports, Program Grant Proposals, Work Plans, CRSP Directories, and Instructions for Data Entry.

A number of documents were prepared and disseminated during this reporting period. These are briefly described below. Reports of CRSP research that were *not* processed by the Program Management Office are listed in Appendix A.

Administrative Reports

Annual Administrative Report

Pond Dynamics/Aquaculture CRSP, Program Management Office. May 1990. Seventh Annual Administrative Report. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 139 pp.

CRSP Work Plan

Pond Dynamics/Aquaculture CRSP, Program Management Office. August 1990. Fifth Work Plan: September 1, 1989 -August 31, 1991. Office of International Research and Development, Oregon State University, Corvallis, Oregon. 168 pp.

Directory

Pond Dynamics/Aquaculture CRSP, Program Management Office. 1990 CRSP Directory. Office of International Research and Development, Oregon State University, Corvallis, Oregon.

The CRSP Directory was updated twice during this reporting period, in January and June. The directory contains an organizational flow chart and addresses of current CRSP members from USAID, BIFAD, USAID Missions, the External Evaluation Committee, Technical Committee, Management Entity, Board of Directors, and the Collaborative Research Projects. The directory also contains electronic mail and FAX access codes.

Newsletter

With the emergence of the CRSP technical publications, the relative need for a program newsletter has declined. *Aquanews* will continue as an occasional publication. It will serve to inform CRSP participants and others of program activities that are not of a technical nature. *Aquanews* will contain information on meetings, travel of CRSP participants, and site visits. The Data Analysis and Synthesis Team began publishing a quarterly newsletter with the goal of improving communication between the DAST and the Principal Investigators in the field. Identifying critical assumptions and information voids was the first step in "closing the loop" in the flow of information that begins with data collection. Additionally, the CRSP will continue to take advantage of other vehicles for communication such as the USAID *Star* newsletter (of the Office of Agriculture's Bureau of Science and Technology) and *Frontlines*. Improved communications among Collaborative Research Support Programs has resulted in exchanges between newsletters.

Technical Reports

CRSP Research Reports

Lin, C.K., V. Tansakul, and C. Apinhapath. 1989. Biological nitrogen fixation as a source of nitrogen input in fishponds. CRSP Research Reports 89-20, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Teichert-Coddington, D. and R.P. Phelps. 1989. Effects of seepage on water quality and productivity of inorganically fertilized tropical ponds. CRSP Research Reports 89-21, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Chang, W.Y.B. 1990. Integrated lake farming for fish and environmental management in large shallow Chinese lakes: a review. CRSP Research Reports 89-22, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Hopkins, K.D. and M.L. Hopkins. 1990. A multivariate model of tilapia growth, applied to seawater tilapia culture in Kuwait. CRSP Research Reports 89-23, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Hopkins, K.D. 1990. Reporting fishpond yields to farmers. CRSP Research Reports 89-24, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Peralta, M. and D. Teichert-Coddington. 1990. Comparative production of *Colossoma macropomum* and *tilapia nilotica* in Panama. CRSP Research Reports 89-25, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Teichert-Coddington, D.R., B.W. Green, N. Matamoros, and R. Rodriguez. 1990. The substitution of chicken litter for feed in the commercial production of peneid shrimp in Honduras. CRSP Research Reports 89-26, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Green, B.W. and L.A. Lopez. 1990. Implementing the large-scale production of young males of *tilapia nilotica* using hormonal sex inversion in Honduras. CRSP Research Reports 89-27, Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 1p.

Collaborative Research Data Reports

Teichert-Coddington, D.R., M. Peralta, R.P.Phelps, and R.P. Malca. 1990. Gualaca, Panama: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Seven, Number Two. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 104 pp.

Green, B.W., H.R. Alvarenga, R. Phelps, and J. Espinoza. 1990. Honduras: Cycle I of The Global Experiment. Collaborative Research Data Reports, Volume Six, Number One. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 140 pp.

Green, B.W., H.R. Alvarenga, R. Phelps, and J. Espinoza. 1989. Honduras: Cycle III of The Global Experiment. Collaborative Research Data Reports, Volume Six, Number Three. Program Management Office, Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon. 125 pp.

IX. Staff Summary

The Pond Dynamics/Aquaculture CRSP represents the joint efforts of more than 25 professionals and a number of support personnel from U.S. universities. It also represents the collaborative efforts of over 35 scientists, technicians, and graduate students from three project sites in three developing countries. The expertise of host country and U.S. personnel is broad-based and encompasses the major fields of specialization included in this CRSP: Limnology and Water Quality; Fisheries and Aquaculture; Data Management, Analysis, and Modeling; Research Administration; and Agricultural Economics.

In addition to staff with formal CRSP assignments, many individuals have participated in the development of host country projects. For example, local scientists in Rwanda continue to use the Rwasave lab for water, soil, and food analysis.

The major United States-based research activity, Data Analysis and Synthesis, involves 12 researchers from the University of California at Davis, Oregon State University, and the University of Michigan. Scientists from Michigan State University, Auburn University, the University of Arkansas at Pine Bluff, and the University of Hawaii also participate in U.S.-based research activities.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
BOARD OF DIRECTORS						
Dr. Philip Helfrich	Chairman	X		X		Kaneohe, Hawaii
Dr. R. Oneal Smitherman	Member	X		X		Auburn, Alabama
Dr. Robert Fridley	Member	X	X	X		Davis, California
AT-LARGE TECHNICAL COMMITTEE						
Dr. Donald Garling	Member			X		East Lansing, Michigan
Dr. George Tchobanoglous	Member			X		Davis, California
MANAGEMENT ENTITY						
Dr. Howard Horton	Director (to 12/89)	X		X		Corvallis, Oregon
Ms. Hillary Egna	Director (from 7/90) Acting Director (from 1/90)	X	X	X		Corvallis, Oregon
Ms. Hilary Berkman	Data Base Manager		X	X	X	Corvallis, Oregon
Mrs. Lydia Perry	Secretary (to 1/90)	X				Corvallis, Oregon
Ms. Marion McNamara	Secretary (from 1/90) Assistant Director (from 8/15/90)	X				Corvallis, Oregon
Mr. Jim Bowman (2)	Graduate Student (from 1/22/90)	X	X	X		Corvallis, Oregon
DATA ANALYSIS AND SYNTHESIS						
DATA ANALYSIS AND SYNTHESIS - OREGON STATE UNIVERSITY						
Dr. James Lannan	Data Synthesis Team Member	X		X	X	Newport, Oregon
Mr. Jim Bowman (2)	Graduate Student	X	X	X		Corvallis, Oregon
Mr. Shree Nath	Graduate Student		X	X		Corvallis, Oregon
Mr. Andy Snow	Graduate Student		X	X		Corvallis, Oregon
Ms. Susan Mills	Secretary	X				Newport, Oregon
Mr. Bruce Sorte (2)	Fiscal Officer	X				Corvallis, Oregon

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Field(s) of Specialization: Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
DATA ANALYSIS AND SYNTHESIS - UNIVERSITY OF MICHIGAN						
Dr. William Chang	Data Synthesis Team Member	X	X	X	X	Ann Arbor, Michigan
Mr. Steve Riggs	Data Synthesis Assistant		X	X	X	Ann Arbor, Michigan
Mr. Bob Springborn	Data Synthesis Assistant			X	X	Ann Arbor, Michigan
Mr. Kwang-Ming Liu	Data Synthesis Assistant			X		Ann Arbor, Michigan
Ms. Tracy Willoughby	Fiscal Officer	X				Ann Arbor, Michigan
DATA ANALYSIS AND SYNTHESIS - UNIVERSITY OF CALIFORNIA AT DAVIS						
Dr. Raul Piedrahita	Principal Investigator		X	X	X	Davis, California
Mr. Philip Giovannini	Post-Graduate Researcher		X	X	X	Davis, California
Ms. Zhimin Lu	Post-Graduate Researcher				X	Davis, California
Dr. Philip Westerman	Data Synthesis Visiting Professor		X		X	Davis, California
Mr. George Max	Fiscal Officer	X				Davis, California

HONDURAS

Individual	CRSP Function	Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
HONDURAS - AUBURN UNIVERSITY						
Dr. Bryan Duncan	U.S. Principal Investigator	X		X		Auburn, Alabama
Dr. Claude Boyd	U.S. Researcher	X	X	X		Auburn, Alabama
Dr. David Teichert-Coddington	U.S. Research Associate		X	X		Comayagua, Honduras
Mr. Bartholomew Green	U.S. Research Associate		X	X		Auburn, Alabama
Mr. Donald Large (2)	Fiscal Officer	X				Auburn, Alabama

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
HONDURAS- UNIVERSITY OF HAWAII						
Dr. Kevin Hopkins (2)	U.S. Co-Principal Investigator	X	X	X	X	Hilo, Hawaii
Dr. James Szyper (2)	U.S. Co-Principal Investigator	X	X	X		Kaneohe, Hawaii
Mr. Gerry Akiyama (2)	Administrative Support	X				Honolulu, Hawaii
Ms. Cora Chai (2)	Associate Fiscal Officer	X				Honolulu, Hawaii
HONDURAS- HOST COUNTRY PERSONNEL						
Ing. Marco Ivan Rodriguez	H.C. Principal Investigator			X		Comayagua, Honduras
Mr. Ricardo Gomez	H.C. Research Associate	X		X		Comayagua, Honduras
Mr. Nelson Claros	H.C. Chemist		X			Comayagua, Honduras
Ms. Sagrario Calix	H.C. Secretary	X				Comayagua, Honduras
Mr. Miguel Zelaya	H.C. Lab Technician			X		Comayagua, Honduras
Mr. Luis Lopez	H.C. Field Biologist			X		Comayagua, Honduras
Ms. Myra Lara	H.C. Biologist/ Chemist			X		Comayagua, Honduras
		RWANDA				
RWANDA- OREGON STATE UNIVERSITY						
Mr. Wayne Seim	U.S. Principal Investigator	X	X			Corvallis, Oregon
Mr. Bruce Sorte (2)	Fiscal Officer	X				Corvallis, Oregon
Mr. Felicien Rwangano	Graduate Student			X		Corvallis, Oregon
RWANDA- AUBURN UNIVERSITY						
Dr. Tom Popma	U.S. Principal Investigator	X		X		Auburn, Alabama
Ms. Karen Veverica	U.S. Research Associate		X	X		Auburn, Alabama
Mr. Donald Large (2)	Fiscal Officer	X				Auburn, Alabama

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
		Field(s) of Specialization				
RWANDA- UNIVERSITY OF ARKANSAS AT PINE BLUFF						
Dr. Carole Engle	U.S. Principal Investigator	X		X		Pine Bluff, Arkansas
Dr. Ann Gannam	Researcher			X		Pine Bluff, Arkansas
RWANDA- HOST COUNTRY PERSONNEL						
Dr. Evariste Karangwa	H.C. Principal Investigator	X		X		Butare, Rwanda
Mr. Eugene Rurangwa	H.C. Research Associate			X		Butare, Rwanda
Dr. Maurice Ntahobari	UNR Rector	X				
Dr. Runyinya Barabwiliza	Dean of Faculty of Agronomy	X				Butare, Rwanda
Mr. Ngoy Kasongo	H.C. Technician		X			Butare, Rwanda
Ms. Alfonsine Murekeyisoni	H.C. Technician		X			Butare, Rwanda
Mr. Joseph Murangwa	H.C. Computer Technician				X	Butare, Rwanda
THAILAND						
THAILAND - UNIVERSITY OF MICHIGAN						
Dr. James Diana	U.S. Co-Principal Investigator		X	X	X	Ann Arbor, Michigan
Dr. C. Kwei Lin	U.S. Co-Principal Investigator		X	X		AIT, Thailand
Mr. Daniel Dettweiler	U.S. Research Assistant		X	X		Ann Arbor, Michigan
Ms. Tracy Willoughby	Fiscal Officer	X				Ann Arbor, Michigan
THAILAND - MICHIGAN STATE UNIVERSITY						
Dr. Clarence McNabb	U.S. Co-Principal Investigator		X	X		East Lansing, Michigan
Dr. Ted Batterson	U.S. Co-Principal Investigator	X	X		X	East Lansing, Michigan
Dr. Chris Knud-Hansen	U.S. Research Associate		X	X		AIT, Thailand
Ms. Colleen J. Badra	Fiscal Officer (from 4/90)	X				East Lansing, Michigan
Mr. Gerald L. Jacobs	Fiscal Officer (8/30/89-3/30/90)	X				East Lansing, Michigan

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.

STAFF SUMMARY: COLLABORATIVE RESEARCH PROJECTS

Individual	CRSP Function	Research Admin.	Limnology/ Water	Fisheries/ Aquaculture	Data Management	Location of Work (1)
		Field(s) of Specialization				
THAILAND - UNIVERSITY OF HAWAII						
Dr. Kevin Hopkins (2)	U.S. Co-Principal Investigator	X	X	X	X	Hilo, Hawaii
Dr. James Szyper (2)	U.S. Co-Principal Investigator	X*	X	X		Kaneohe, Hawaii
Mr. Gerry Akiyama (2)	Administrative Support	X				Honolulu, Hawaii
Ms. Cora Chai (2)	Associate Fiscal Officer	X				Honolulu, Hawaii
THAILAND - HOST COUNTRY PERSONNEL						
Dr. Kitjar Jaiyen	H.C. Co-Principal Investigator		X	X		NIFI, Thailand
Dr. Peter Edwards	H.C. Co-Principal Investigator			X		AIT, Thailand
Ms. Tanaporn	H.C. Research Assistant			X		Bangkok, Thailand
Mr. Wongbathom Konmonrat	H.C. Research Assistant				X	Bangkok, Thailand
Dr. Sompote Ukatawewat	H.C. Research Associate	X		X		Ayutthaya, Thailand
Mr. Kiengkai	H.C. Research Assistant		X	X		AIT, Thailand
Mr. T. J. Thomas	H.C. Research Assistant			X		AIT, Thailand

(1) Denotes primary work location and excludes host country site visits and travel for attendance of meetings.
(2) Personnel involved in two projects.

X. Financial Summary

This section summarizes the expenditure of USAID, non-federal, and Host Country funds for CRSP research activities and program management. This unaudited summary is intended to provide an overview of CRSP progress relative to program budgets and matching support. Final figures for the end of grant period (as reported in Table 1) may not include all encumbrances.

The expenditure of USAID funds by Collaborative Research Projects, Special Topics Research, and Program Management is presented in Table 1 for the PD/A CRSP contract year of 1 September 1989 to 31 August 1990, in accordance with our Continuation Plan. The financial figures for the U.S. Research Component include expenditures to support the Data Analysis and Synthesis Team's activities at the University of California at Davis, Oregon State University, and The University of Michigan.

The information on Program Management Office expenditures include three main categories: Operations and Administration, Communications, and Data Base Management. This CRSP is unique in including the research-oriented functions of Data Base Management and technical communications in the Program Management Office. Additional detail on the Program Management Office is provided in Section VIII of this report.

Cost-sharing contributions from the U.S. institutions are presented in Table 1. The overall CRSP cost sharing for the three-year grant is 25 percent. These data reflect a strong and continuing commitment by program entities to participation in the CRSP. However, confirmation of these data requires further accounting, which is available in the final Financial Status Report submitted by the Management Entity to AID.

Host Country contributions (in U.S. dollars) are also presented in Table 1. These data were provided by the Principal Investigators of the projects. Although Host Country cost sharing is not required, these data indicate a continuing commitment to participation in the CRSP by our collaborators.

Table 1. Financial Summary of The Pond Dynamics/Aquaculture CRSP Funds, Cost Sharing, and Host Country Contributions from the period September 1, 1989 to August 31, 1990.

		USAID Funds, 1990 (In US dollars)		Cost Sharing (In US dollars)		Total (In US dollars)		Host Country Contribution (In US dollars)	
		Obligated	Cumulative	1990	Cumulative	1990	Cumulative	1990	Cumulative
Research Program									
Honduras:	Auburn U.	191,817	493,618	44,522	132,873	236,339	626,491	42,500	122,083
	U. Hawaii	39,865	53,893	6,560	9,584	46,425	63,477		
Rwanda:	Auburn U.	116,241	252,152	33,729	93,782	149,970	345,934		
	Oregon St. U.	132,822	268,795	15,555	120,109	148,377	388,904	49,500	270,899
	UAPB	22,255	22,255	5,564	5,564	27,819	27,819		
Thailand:	Michigan St. U.	95,007	198,691	15,598	70,571	110,605	269,262		
	U. Michigan	143,992	424,080	21,402	69,034	165,394	493,114	43,000	129,000
	U. Hawaii	79,845	137,693	17,072	50,463	96,917	188,156		
Subtotal				160,002	551,980	160,002	551,980	135,000	521,982
US Research Component									
U. California at Davis		52,662	132,775	13,500	35,650	66,162	168,425		
Oregon St. U.		54,439	132,575	22,240	39,773	76,679	172,348		
U. Michigan		88,581	130,008	22,145	32,502	110,726	162,510		
Subtotal				57,885	107,925	57,885	107,925		
Management Entity		207,451	530,465			207,451	530,465		
TOTAL		1,172,315	2,644,225	217,887	659,905	1,390,202	3,304,130	135,000	521,982

1 The second CRSP grant ended on 31 August 1990; the new grant was implemented 1 September 1990. Final figures for the end of grant period for some of the projects were still being prepared at the time this report was compiled. These amounts were reported by PIs in their annual summaries, but because of the time lag in reporting from overseas projects, may not include all encumbrances as of the end of the grant period.

APPENDICES

Appendix A. CRSP List of Publications through December 1990

AUBURN/HONDURAS

Theses

Berrios, J. In preparation. Growth and survival of hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) fingerlings during the nursery phase. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Cerna, C. In preparation. Zooplankton dynamics in *Tilapia nilotica* production ponds fertilized with triple superphosphate. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Echeverria, M.A. In preparation. Primary production in *Tilapia nilotica* production ponds fertilized with triple superphosphate. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Garces, C. 1986. Quantitative analysis of zooplankton in fish ponds fertilized with triple superphosphate during the rainy season. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Gomez, R. 1988. Effect of fertilizer type on the production of male *Tilapia nilotica*. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Lopez, L. In preparation. Production of *Tilapia nilotica* in ponds fertilized with layer chicken litter. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Mejia, C. In preparation. Rainy season phytoplankton dynamics in ponds stocked with *Tilapia nilotica*. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Paz, S.A. In preparation. The relationship between primary productivity and chlorophyll and their relation to tilapia production. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Sherman, C. In preparation. All female culture of *Tilapia nilotica* in ponds fertilized with chicken litter. B.S. thesis, Dept. of Biology, Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras. (In Spanish.)

Publications and Reports

Alvarenga, H.R., and B.W. Green. 1985. Production of hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) fingerlings. CRSP Technical Report, unpublished. 12 pp. (In Spanish.)

Alvarenga, H.R., and B.W. Green. 1986. Growth and production of all male *Tilapia nilotica* and all male hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) in ponds. Rev. Latinoamericana de Acuicultura 29:6-10. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1984. A system for producing hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) fingerlings at the El Carao Aquaculture Experiment Station, Comayagua, Honduras. CRSP Technical Report, unpublished. 9 pp. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1985. Pelleted fish feed vs. corn gluten as feed for tilapia and Chinese carp polyculture in ponds. CRSP Technical Report, unpublished. (In Spanish.)

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. In preparation. Production of hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) fingerlings using two different brood stock densities. CRSP Technical Report, unpublished. Auburn University, Alabama.

Alvarenga, H.R., B.W. Green, and M.I. Rodriguez. 1987. Production of hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) in ponds using corn gluten as a supplemental feed. CRSP Technical Report, unpublished. 13 pp. (In Spanish.)

Berrios, J.M. 1986. Growth and survival of hybrid tilapia (*Tilapia nilotica* x *Tilapia honorum*) fingerlings during the nursery phase in ponds. CRSP Technical Report, unpublished. 16 pp. (In Spanish.)

Green, B.W. 1985. Report on the induced spawning of the silver and grass carps. CRSP Technical Report, unpublished. 8 pp. (In Spanish.)

Green, B.W., and H.R. Alvarenga. 1985. Tilapia and carp polyculture in ponds receiving organic fertilization and supplemental feed. CRSP Technical Report, unpublished. 10 pp. (In Spanish.)

Green, B.W., and L.A. López. 1990. Factibilidad de la producción masira de alevines machos de *Tilapia nilotica* a través de la inversión hormonal de sexo en Honduras. Agronomía Mesoamericana 1:21-26.

Green, B.W., H.R. Alvarenga, R.P. Phelps and J. Espinoza. 1985. Technical Report: Honduras Aquaculture CRSP Cycle I Dry Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama. 51 pp.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1986. Technical Report: Honduras Aquaculture CRSP Cycle I Rainy Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama. 77 pp.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1986. Technical Report: Honduras Aquaculture CRSP Cycle II Dry Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1987. Technical Report: Honduras Aquaculture CRSP Cycle II Rainy Season Phase. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., H.R. Alvarenga, R.P. Phelps, and J. Espinoza. 1988. Technical Report: Honduras Aquaculture CRSP Cycle III Rainy and Dry Season Phases. CRSP Technical Report, unpublished. Auburn University, Alabama.

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1989. The effect of manures and chemical fertilizers on the production of *Oreochromis niloticus* in earthen ponds. Aquaculture 76:37-42.

Sherman, C. 1986. Growth of all-female *Tilapia nilotica* in earthen ponds fertilized with chicken litter. CRSP Technical Report, unpublished. 14 pp. (In Spanish.)

Teichert-Coddington, D.R., B.W. Green, N. Matamoros, and R. Rodriguez. 1990. Substitución de alimentos por gallinaza en la producción comercial de camarones peneidos en Honduras. Agronomía Mesoamericana 1:73-78.

Scientific Papers Presented

Alvarenga, H.R., and B.W. Green. 1988. Produccion y aspectos economicos del cultivo de tilapia en estanques fertilizados con gallinaza. (Production and economic aspects of tilapia culture in ponds fertilized with chicken litter.) Presented by H. Alvarenga at the 34th Annual Meeting of the Programa Colaborativo Centro Americano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Jose, Costa Rica.

Green, B.W. 1990. Substitution of organic manure for pelleted feed in tilapia production. Accepted for inclusion in the European Inland Fisheries Advisory Commission's Symposium on production enhancement in still water pond culture, Prague, Czechoslovakia, May 1990.

Green, B.W. and H.R. Alvarenga. 1987. Efecto de diferentes tasas de aplicacion de gallinaza en la produccion de tilapia. (The effect of different rates of chicken litter application on the production of tilapia.) Presented at the 33rd Annual Meeting of the Programa Colaborativo Centro Americana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), Instituto de Ciencia y Technologia Agricola, Guatemala, 30 March-4 April, 1987. Presented by H. Alvarenga. (In Spanish.)

Green, B.W., and H.R. Alvarenga. 1987. Intensive fingerling production of hybrid tilapia *Tilapia nilotica* x *Tilapia honorum* in earthen ponds. Presented at the 18th Annual Meeting of the World Aquaculture Society, Guayaquil, Ecuador. Presented by B. Green.

Green, B., and H. Alvarenga. 1989. Sistemas de produccion de tilapia utilizando fertilizacion organica y alimentacion. Presented at the annual regional meeting of the Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by H. Alvarenga.

Green, B., and L. Lopez. 1989. Factabilidad de la produccion masiva de alevines machos de *tilapia nilotica* atraves de la inversion hormonal de sexo en Honduras. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by L. Lopez.

Green, B.W., and D.R. Teichert-Coddington. 1990. Comparison of two sampler designs for use with automated data acquisition systems in whole-pond community metabolism studies. Accepted for inclusion as a poster presentation in the European Inland Fisheries Advisory Commission's Symposium on production enhancement in still water pond culture, Prague, Czechoslovakia, May 1990.

Green, B.W., H.R. Alvarenga, and R.P. Phelps. 1988. The effect of stocking rate on the production of *Tilapia nilotica* in ponds. Presented at the 34th Annual Meeting of the Programa Colaborativo Centro Americano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Jose, Costa Rica. (In Spanish.) Presented by B. Green.

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1987. The effect of nitrogen and phosophorus sources in fertilizers used for the production of *Tilapia nilotica*. Presented by B. Green at the 18th Annual Meeting of the World Aquaculture Society, Guayaquil, Ecuador.

Teichert-Coddington, D., and B. Green. 1990. Influence of primary productivity, season and site on tilapia production in organically fertilized ponds in two Central American countries. Accepted for inclusion in the European Inland Fisheries Advisory Commission's Symposium on production enhancement in still water pond culture, Prague, Czechoslovakia, May 1990.

Teichert-Coddington, D., B. Green, and M.I. Rodriguez. 1989. Effectos de la tasa de alimentacion sobre la produccion de tilapia en estanques fertiliazdos con gallinaza. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by M.I. Rodriguez.

Teichert-Coddington, D., B. Green, N. Matamoros, and R. Rodriguez. 1989. Substitucion de alimento por gallinaza en la produccion comercial de camarones peneidos en Honduras. Presented at the annual regional meeting of the Programa Cooperativo Centroamericana para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras. Presented by D. Teichert-Coddington.

Manuscripts

Green, B.W. 1990. Substitution of organic manure for pelleted feed in tilapia production. Submitted to Aquaculture.

Green, B.W., R.P. Phelps, and H.R. Alvarenga. 1987. The effect of nitrogen and phosphorus sources in fertilizers used for the production of *Tilapia nilotica*. Submitted for publication in Aquaculture.

Green, B.W., and D. R. Teichert-Coddington. 1990. A comparison of two samplers used with an automated data acquisition system in whole-pond, community metabolism studies. Submitted to the Progressive Fish-Culturist.

Green, B., and D. Teichert-Coddington. In preparation. Growth of normal and sex-reversed *Oreochromis niloticus* during hormone treatment, and nursery and grow-out phases.

Green, B., D. Teichert-Coddington, and R. Phelps. 1990. Response of tilapia yield and economics to varying rates of organic fertilization and season in two Central American countries. Aquaculture, in press.

Teichert-Coddington, D.R., B.W. Green, and R.W. Parkman. 1990. Substitution of chicken litter for feed in production of penaeid shrimp in Honduras, Central America. Submitted to the Progressive Fish-Culturist.

Teichert-Coddington, D., B. Green, and R. Phelps. In preparation. Effects of site and season on water quality and tilapia production in inorganically fertilized ponds in Central America.

Teichert-Coddington, D., B.W. Green, and R. Phelps. In preparation. Influence of water quality, season and site on tilapia production in Panama and Honduras.

AUBURN/PANAMA - AGUADULCE

Theses

Abrego Ramos, R. 1985. Uso de androgenos en alevines de *Tilapia nilotica* para la produccion de tilapias monosexuales. Licenciatura Thesis in Biology, Univ. of Panama.

Avila, M. In preparation. El efecto del policultivo del pez, *Mugil curema*, a varios densidades de siembra con la produccion de *Penaeus vannamei* y en la calidad de agua en estanques de tierra. Licenciatura Thesis in Biology, Catholic University of Chile, Santiago, Chile.

Chavez, H. 1984. Estudio trofodinamico de *Penaeus vannamei* cultivado en estanques experimentales de aguas salobres. Licenciatura Thesis in Biology, Univ. of Panama.

Hernandez de Santamaria, D. In preparation. El efecto de dietas experimentales en el crecimiento y sobrevivencia de *Penaeus vannamei* cultivado en estanques. Licenciatura Thesis in Biology, Univ. of Panama.

Lasso de la Vega, E. 1985. Variacion del zooplancton en estanques de cria de camarones blanco durante la estacion seca. Licenciatura Thesis in Biology, Univ. of Panama.

Lore, D., H.T., and R. Visuetti. 1984. Efecto de la aplicacion de abonos organicos, concentrados y pescado fresco (*Dormitator latifrons*) en la produccion de *Penaeus stylirostris* y *Penaeus vannamei*. Licenciatura Thesis in Biology, Univ. of Panama.

Quesada, I. In preparation. Ocurrencia de organismos bentonicos en estanques no alimentados sembrados con *Penaeus vannamei* durante la estacion seca. Licenciatura Thesis in Biology, Univ. of Panama.

Quiroz, V. In preparation. Efectos de varios niveles de recambio de agua a la calidad de agua y en la produccion de *Penaeus vannamei* en estanques de tierra. Licenciatura Thesis in Biology, Univ. of Panama.

Publications and Reports

Teichert-Coddington, D., and M. Arrue. 1988. Efectos de dietas de proteinas y densidades de siembra sobre la producción de *Penaeus uannamei* en estanques de Herra. Rev. Lst. Acui., 35:29-33.

Van Wyk, P. 1986. The relationship of pump discharge and fuel efficiency to tidal height for a brackishwater aquaculture pumping station. Masters of Aquaculture Special Project, Auburn University, Alabama.

Scientific Papers Presented

Chavez, H. 1984. Estudio trofodinamico de *Penaeus vannamei* cultivado en estanques experimentales de aguas salobres. Presented to the First National Scientific Congress, Univ. Panama, Panama. (December)

De Leon, A. 1985. El efecto de aplicar fertilizantes inorganicos en la produccion de *Penaeus vannamei* en estanques. Presented to the Second National Scientific Congress, Univ. of Panama, Panama. (November)

Hughes, D.G. 1984. The marine shrimp culture industry in Panama. Presented to the First Annual Shrimp World Marketing Conference, Acapulco, Mexico. (November)

Hughes, D.G. 1985. Prediction of pond productivities: a challenge for aquaculture. Presented to the Pontifical Catholic Univ. of Ecuador, Quito, Ecuador. (November)

Hughes, D.G., and O.M. Garcia A. 1984. La produccion de semilla de *Tilapia nilotica* en hapas: una comparacion de productividades de clima templada con clima tropical. Presented by David Hughes to First National Aquaculture Seminar in Univ. Nacional, Heredia, Costa Rica. (June)

Hughes, D.G., A. Torres, and R.P. Phelps. 1985. Production and growth characteristics of *Penaeus stylirostris* and *P. vannamei* in monoculture and polyculture in fed and unfed earthen ponds. Presented by D. Hughes at the Annual Meeting of the World Mariculture Society, Orlando, Florida. (January)

Hughes, D.G., G. de Gomez, E. Lasso de la Vega, R.P. Phelps, and R. Pretto Malca. 1987. Rainy and dry season comparisons in *Penaeus vannamei* production ponds in Panama receiving various water exchange rates: water quality variation. Poster session at World Aquaculture Society Meeting, Guayaquil, Ecuador. (January)

Kivers, A. 1984. Comparacion de dos rangos y dietas alimentacias con alevines de *Tilapia nilotica* en piletas de concreto. Presented to the First National Scientific Congress, Univ. of Panama, Panama. (December)

Kivers, A. 1984. Comparacion de tres densidades de seimbra de alevines de *Tilapia nilotica* en piletas de concreto. Presented to the First National Scientific Congress, Univ. of Panama, Panama. (December)

Lasso de la Vega, E., and M. Villareal. 1985. Variacion del zoo-plancton en estanques de cria de camarones blanco durante la estacion seca. Presented to the Second National Scientific Congress, University Panama, Panama. (November)

Lore, D., H. Tunon, and R. Visuetti. 1984. Efecto de la aplicacion de abonos organicos, concentrados y pescado fresco (*Dormitator latifrons*) en la produccion de *Penaeus stylirostris* y *Penaeus vannamei*. Presented by H. Tunon to the First National Scientific Congress, Univ. Panama, Panama. (December)

Moreno, J.M. 1984. Alimentacion de la *Tilapia nilotica* en la etapa de alevinaje. Presented to the First National Scientific Congress, Univ. of Panama, Panama. (December)

Moreno, J.M. 1984. El uso del androgeno 17-metil-testosterona en alevinaje de *Tilapia nilotica* para la produccion de Tilapia monosexuales en Panama. Presented to the First National Scientific Congress, Univ. of Panama, Panama. (December)

Pretto, R., G. Garson, V. Batista, and M. de Leon. 1983. Estudio preliminar del policultivo de Peneidos con peces nativos de aguas salobres. Presented by R. Pretto to the Fifth Symposium of Latin American Aquaculture, Univ. Austral de Chile, Valdivia, Chile. (September)

Torres, A. 1984. Produccion de *Penaeus stylirostris* bajo la influencia del *Penaeus vannamei*, en estanques experimentales de agua salobre con y sin alimentacion durante la epoca seca. Presented to the First National Scientific Congress, Univ. of Panama, Panama. (December)

AUBURN/PANAMA - GUALACA

Theses

Atencio, A. 1987. Phosphorus saturation of acidic soils in tropical fish culture ponds.

Barrios, C.M. 1985. Analysis of water quality in new freshwater ponds at the Freshwater Aquaculture Station in Gualaca.

Friele, M.E.F. 1985. Stomach analyses of *Macrobrachium rosenbergii*, *Tilapia nilotica*, *Colossoma macropomum* and the hybrid *Hypophthalmichthys molitrix* x *Aristichthys nobilis* in polyculture at the Gualaca Freshwater Aquaculture Experiment Station, Panama.

Hughes, David G. Evaluation of seed production and sex-reversal methods for *Tilapia nilotica* and field verification in a tropical hatchery.

Perez, M.J. 1985. Economic and marketing study of fish and shrimp in polyculture systems in freshwater ponds at Gualaca, Chiriqui Province.

Pimentel, C.A.B. 1984. Effect of liming on new unfertilized ponds at the Gualaca Aquaculture Experiment Station.

Rios, R.A. In preparation. Identification and dynamics of zooplankton found in tropical earthen ponds receiving chicken litter at four rates.

Rodriguez, Ivonne. Feeding *Penaeus vannamei* and *Penaeus stylirostris* in nursery ponds.

Serrano, A. 1987. Economics of tilapia production in monoculture or in polyculture with prawns, and utilizing manure or a commercial pellet as the nutrient input in Gualaca, Panama.

Publications and Reports

Peralta, M., and D. R. Teichert-Coddington. Comparative production of Colossoma macropomum and *Tilapia nilotica* in Panama. Journal of the World Aquaculture Society 20(4):236-239.

Teichert-Coddington, D.R., and R.P. Phelps. 1989. Effects of seepage on water quality and productivity of inorganically fertilized tropical ponds. Journal of Aquaculture in the Tropics 4:85-92.

Teichert-Coddington, D.R., M. Peralta, and R. P. Phelps. 1989. Seepage reduction in tropical fish ponds using chicken litter. Aquacultural Engineering 8:147-154.

Teichert-Coddington, D.R., N. Stone, and R.P. Phelps. 1988. Hydrology of Fish Culture Ponds in Gualaca, Panama. Aquacultural Engineering 7:309-320.

Teichert-Coddington, D.R., M. Peralta, R.P. Phelps, and R. Pretto. 1985. CRSP Technical Report: First cycle, dry season 1985, Freshwater Aquaculture Research Station, Gualaca, Panama.

Teichert-Coddington, D.R., M. Peralta, R.P. Phelps, and R. Pretto. 1985. CRSP Technical Report: First cycle, wet season 1985, Freshwater Aquaculture Research Station, Gualaca, Panama.

Teichert-Coddington, D.R., M. Peralta, R.P. Phelps, and R. Pretto. 1990. Gualaca, Panama: Cycle III of the global experiment. Pond Dynamics/Aquaculture Collaborative Research Data Reports, Vol. 7(2).

Presentations

Peralta, M., and D.R. Teichert-Coddington. 1988. Comparative production of *Colossoma macropomum* and *Tilapia nilotica* in Panama. Presented at the 20th World Aquaculture Society Meeting in Honolulu, Hawaii. (January)

Teichert-Coddington, D.R., D.B. Rouse, A. Khater, and R.O. Smitherman. 1987. Effects of two rates of organic fertilization and two levels of alkalinity on prawn production in a prawn-tilapia polyculture. Presented at the World Aquaculture Society Meeting, Ecuador.

Manuscripts

Teichert-Coddington, D.R., M. Peralta, and R. Pretto. 1986. Prawn and tilapia culture in Panama: commercialization of freshwater aquaculture. Submitted to Infofish, FAO Publ.

MSU/INDONESIA

Theses

Abdalla, Abdelmoez A. F. 1989. The effect of ammonia on *Oreochromis niloticus* (Nile tilapia) and its dynamics in fertilized tropical fish ponds. Ph.D. Dissertation, Michigan State University, East Lansing, Michigan. 62 pp.

Etnawati, N. 1987. The effect of *Oreochromis niloticus* Trewavas production by increasing surface area for attached microorganisms. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 41 pp.

Gartini, T. 1986. Flow rate dependent changes in turbidity and phosphorus in the water conditioning system at Darmaga. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 66 pp.

Harahat, I.S. 1987. Changes of nitrogen concentration of the Nile tilapia ponds which were fertilized with chicken manure. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 41 pp.

Haryani, G.S. 1985. The growth rate, mortality and feeding habits of *Tilapia nilotica* (L.). B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 76 pp.

Litasari, L. 1985. The composition and abundance of macrobenthos in relation to pond productivity. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 71 pp.

Radiastuti, F. 1986. The balance of nitrogen from an irrigation canal that flows through a water conditioning system in Darmaga. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 63 pp.

Rao, T. V. G. 1989. Gonadal development in environmentally induced breeding of walking catfish *Clarias batrachus* (Linnaeus). M.S. thesis, Asian Institute of Technology, Bangkok, Thailand.

Subyakto, S. 1985. The relationship between chlorophyll *a* and Secchi disk visibility in tilapia fish ponds at Darmaga, Bogor. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 51 pp.

Suratman, I.F. 1985. Composition and abundance of zooplankton in *Tilapia nilotica* (L.) fish ponds fertilized with triple superphosphate at Darmaga. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 58 pp.

Tumbelaka, R. 1986. Primary productivity of aquaculture ponds at Darmaga. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 87 pp.

Widjaja. 1985. Flushing rate of experimental *Tilapia nilotica* (L.) ponds at Darmaga and its relationship to some physical and chemical factors of the ponds. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 64 pp.

Yulianti, S. 1986. Removal of detergents in irrigation canal water by water conditioning system at Darmaga, Bogor. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 71 pp.

Yulisto. 1985. Effect of fish predation on macrobenthos density in aquaculture ponds. B.S. thesis, Faculty of Fisheries, Agricultural University of Bogor, Indonesia. 82 pp.

Yusoff, M.F. 1987. Fish production, primary productivity and nutrient availability in fertilized fish ponds in Malaysia. Michigan State University, Lansing, Michigan. 69 pp.

Publications and Reports

Batterson, T.R., C.D. McNabb, C.F. Knud-Hansen, H.M. Eidman, and K. Sumantadinata. 1988. Effect of chicken manure additions on fish production in ponds in West Java, Indonesia. CRSP Research Report 88-8. 6 pp.

Batterson, T.R., C.D. McNabb, C.F. Knud-Hansen, H.M. Eidman, and K. Sumantadinata. 1989. Pond Dynamics/Aquaculture Collaborative Research Data Reports Volume Three, Number Three. Indonesia Project: Cycle III of the Global Experiment. PD/A CRSP, Corvallis, Oregon. 135 pp.

Knud-Hansen, C.F., T.R. Batterson, and I.S. Harahat. 1988. Nitrate and ammonia depletion in Indonesian aquaculture ponds fertilized with chicken manure. Journal of the World Aquaculture Society 19:42A.

McNabb, C.D., K. Sumawidjaja, B.J. Premo, and K. Sumantadinata. 1984. Aquaculture-CRSP Indonesia project report first five-month experiment. Michigan State University, East Lansing, Michigan. 107 pp. (March)

McNabb, C.D., T.R. Batterson, M. Eidman, C.S. Annett, and K. Sumantadinata. 1985. Aquaculture-CRSP Indonesia project report first five-month experiment, second experimental cycle (January-June 1985). Michigan State University, East Lansing, Michigan. 105 pp. (September)

McNabb, C.D., T.R. Batterson, M. Eidman, B.J. Premo, and K. Sumantadinata. 1985. Aquaculture-CRSP Indonesia project report second five-month experiment. Michigan State University, East Lansing, Michigan. 71 pp. (January)

McNabb, C.D., T.R. Batterson, B.J. Premo, M. Eidman, and K. Sumantadinata. 1988. Pond Dynamics/Aquaculture Collaborative Research Data Reports Volume Three. Indonesia: Cycle I of the Global Experiment. PD/A CRSP, Corvallis, Oregon. 67 pp.

McNabb, C.D., and eight coauthors. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. Pages 169-192 *in* R. Hirano and I. Hanyu, editors. Proceedings of The Second Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Yusoff, F.M., and C.D. McNabb. 1989. Effects of nutrient availability on primary productivity and fish production in fertilized tropical ponds. Aquaculture 78:303-319.

Scientific Papers Presented

Batterson, T.R. 1985. The problems of water quality for Indonesian fisheries. Seminar series of the Bogor Chapter of the Indonesian Fisheries Society, Bogor, Indonesia. (December)

Knud-Hansen, C.F., T.R. Batterson, and I.S. Harahat. 1988. Nitrate and ammonia depletion in Indonesian aquaculture ponds fertilized with chicken manure. World Aquaculture Society, 19th Annual Meeting, Honolulu, Hawaii. (January)

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson. 1989. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. XXIVth Congress of the International Association of Theoretical and Applied Limnology. (August)

McNabb, C.D. 1984. Application of limnological technology to fish pond management. National Institute of Biological Science, Bogor, Indonesia. (December)

McNabb, C.D. 1986. Carbon limitation in fish culture ponds in Indonesia. Visiting Scientists Seminar Series, Lake Biwa Research Center, Shiga University, Otsu, Japan. (March)

McNabb, C.D. 1986. Limnology of fish ponds in Java. Visiting Scientists Seminar Series, College of Fisheries and Marine Science, Agricultural University of Malaysia, Serdang, Malaysia. (February)

McNabb, C.D., T.R. Batterson, H.M. Eidman, and K. Sumantadinata. 1988. Carbon limitation in fertilized fish ponds in Java. World Aquaculture Society Meeting, 19th Annual Meeting, Honolulu, Hawaii. (January)

McNabb, C.D., T.R. Batterson, B.J. Premo, and J.R. Craig. 1984. Photosynthetically active radiation in tropical and temperate zone habitats. 88th Annual Meeting of the Michigan Academy of Science, Arts, and Letters, Big Rapids, Michigan. (March)

McNabb, C.D., T.R. Batterson, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Fish yield and nitrogen supplemented organic fertilizers. World Aquaculture Society Meeting, Aquaculture '89, Los Angeles, California. (February)

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Managing fertilizers for fish yield in tropical ponds in Asia. Second Asian Fisheries Forum, Tokyo, Japan. (April)

Sumantadinata, K. 1985. Genetic characteristics of strains of Indonesian carps. Special Symposium of the Japanese Fisheries Society, Tokyo, Japan. (February)

Manuscripts

Kund-Hansen, C.F., C.D. McNabb, and T.R. Batterson. (Accepted). Application of limnology for efficient nutrient utilization in tropical pond aquaculture. Proceedings of the International Association of Theoretical and Applied Limnology.

Kund-Hansen, C.F., T.R. Batterson, C.D. McNabb, I. S. Harahat, K. Sumantadinata, and H.M. Eidman. (Accepted). Nitrogen input, primary productivity and fish yield in fertilized freshwater ponds in Indonesia. Aquaculture.

Published Abstracts

Knud-Hansen, C.F., T.R. Batterson, and I.S. Harahat. 1988. Nitrate and ammonia depletion in Indonesian aquaculture ponds fertilized with chicken manure. Journal of the World Aquaculture Society 19:42A.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson. 1989. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. XXIVth Congress of the International Association of Theoretical and Applied Limnology.

McNabb, C.D., T.R. Batterson, H.M. Eidman, and K. Sumantadinata. 1988. Carbon limitation in fertilized fish ponds in Java. Journal of the World Aquaculture Society 19:51A.

McNabb, C.D., T.R. Batterson, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Fish yield with nitrogen supplemented organic fertilizers. Journal of the World Aquaculture Society 20:56A.

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Managing fertilizers for fish yield in tropical ponds in Asia. The Second Asian Fisheries Forum.

Other Publications

Batterson, T.R. 1985-1987. Indonesia PD/A CRSP data diskettes for Cycles I, II, and III using LOTUS 1-2-3.

Batterson, T.R., and C.D. McNabb. 1986. MSU/CIFAD Visiting Scientist Program. Wardana Ismail, Head, Fisheries Research Facilities, Central Research Institute for Fisheries (CRIFI), Agency for Agricultural Research and Development (AARD), Department of Agriculture, Republic of Indonesia, Jakarta. Eight-week program on water quality techniques, and laboratory equipment and design in support of freshwater aquaculture in Indonesia. (June-August)

Kinnunen, R.E., and C.D. McNabb. 1986. Collaborative aquaculture research: Institute of Pertanian Bogor and Michigan State University. Improvement of pond culture technology and production. Broadcast: National Educational Television, Jakarta, Indonesia, 15 minutes. (March)

Kinnunen, R.E., and C.D. McNabb. 1986. Water treatment for small pond fisheries. Broadcast: National News Network, Television of the Republic of Indonesia (TVRI), Jakarta, Indonesia, 3 minutes. (March)

Knud-Hansen, C.F. 1986. Workshop on Water Quality Analyses for Aquaculture Ponds. Invited by Faculty of Fisheries, University of Brawijaya at Malang, East Java, Indonesia. (November 23-29, 1986).

Kund-Hansen, C.F., and T.R Batterson. 1987-1990. Thailand PD/A CRSP data diskettes for Cycles IV, and V experiments using LOTUS 1-2-3.

McNabb, C.D. 1986. Fisheries in the tropics. World Food Day National Teleconference. Michigan State University. Response Panel, East Lansing, Michigan. (March)

McNabb, C.D., H.M. Eidman, P. Suwignjo, D.L. Garling, K. Sumawidjaja, H.C. Lampe, S.M.H. Simandjuntak, R.E. Kinnunen, R.R. Nitibaskara, J. McAlister, T.R. Batterson, and C.F. Knud-Hansen. 1986. A research plan for Faculty of Fisheries, Institut Pertanian Bogor, Bogor, Indonesia. Michigan State University, East Lansing, Michigan. 30 pp. (Written in both English and Bahasa Indonesian.)

National Educational Television and Television of the Republic of Indonesia (TVRI), Jakarta, Indonesia. 1986. Collaborative aquaculture research: Institut Pertanian Bogor and Michigan State University. Improvement of pond culture technology and production. (Videotape: 33 minutes)

Premo, B.J., and K. Sumantadinata. 1984. Laboratory manual of water quality techniques. Julia Press, Bogor, Indonesia. 43 pp.

MSU/THAILAND

Theses

Abdalla, A.M. In preparation. Managing fertilizers for yields of *Oreochromis niloticus* Trewavas (Nile tilapia). Ph.D. Dissertation, Michigan State University, East Lansing, Michigan.

Jiwyam, Wirat. 1990. The role of sediments in pond fertility. M.S. thesis, Asian Institute of Technology, Bangkok, Thailand. 347 pp.

Rao, T. V. G. 1989. Gonadal development in environmentally induced breeding of walking catfish *Clarias batrachus* (Linnaeus). M.S. thesis, Asian Institute of Technology, Bangkok, Thailand.

Shrestha, M. K. 1989. Impact of attached microorganism biomass on tilapia (*Oreochromis niloticus*) production. M.S. thesis, Asian Institute of Technology, Bangkok, Thailand.

Ullah, Md. A. 1989. Nutrient release characteristics of duck manure for Nile tilapia production. M.S. thesis, Asian Institute of Technology, Bangkok, Thailand.

Publications and Reports

Batterson, T.R., C.D. McNabb, C.F. Knud-Hansen, H.M. Eidman, and K. Sumantadinata. 1989. Pond Dynamics/Aquaculture Collaborative Research Data Reports Volume Three, Number Three. Indonesia Project: Cycle III of the Global Experiment. PD/A CRSP, Corvallis, Oregon. 135 pp.

Knud-Hansen, C.F., T.R. Batterson, C.D. McNabb, Y. Hadiroseyani, D. Dana, and H.M. Eidman. 1990. Hatchery techniques for egg and fry production of of *Clarias batrachus* (Linnaeus). Aquaculture 89:9-19.

Knud-Hansen, C.F., T.R. Batterson, C.D. McNabb, I. S. Harahat, K. Sumantadinata, and H.M. Eidman. Nitrogen input, primary productivity and fish yield in fertilized freshwater ponds in Indonesia. (Accepted) Aquaculture.

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. Pages 169-172 *in* R. Hirano and I. Hanyu, editors. Proceedings of the Second Asian Fisheries Forum.

Yusoff, F., and C.D. McNabb. 1989. Effects of nutrient availability on primary productivity and fish production in fertilized tropical ponds. Aquaculture 78:303-319.

Scientific Papers Presented

Kund-Hansen, C.F. 1990. *Oreochromis niloticus* growout under conditions of high nitrogen and phosphorus input. PD/A CRSP Annual Meeting, East Lansing, Michigan. (20-22 May)

McNabb, C.D., T.R. Batterson, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Fish yield with nitrogen supplemented organic fertilizers. Presented at the World Aquaculture Society Meeting, Hawaii (January).

McNabb, C.D., T.R. Batterson, B.J. Premo, C.F. Knud-Hansen, H.M. Eidman, C.K. Lin, K. Jaiyen, J.E. Hanson, and R. Chuenpagdee. 1989. Managing fertilizers for fish yield in tropical ponds in Asia. Second Asian Fisheries Forum, Tokyo, Japan. (April)

Manuscripts

Kund-Hansen, C.F., C.D. McNabb, and T.R. Batterson. Application of limnology for efficient nutrient utilization in tropical pond aquaculture. (Accepted) Proceedings of the International Association of Theoretical and Applied Limnology.

Knud-Hansen, C.F., D. Dana, Y. Hadiroseyani, T.R. Batterson, and C.D. McNabb. Accepted. Egg production and fry development techniques for *Clarius batrachus* (L.) hatcheries.

OSU/RWANDA

Theses

Bizimana, V. 1985. Essais de triage mecanique en vue d'un elevage monosexe des tilapias et controle de la croissance sur *T. macrochir* et *T. rendalli*. (The use of mechanical sorting for the monosex culture of tilapias: growth trials with *T. macrochir* and *T. rendalli*.) Thesis for the degree of Ingenieur Agronome, Université Nationale du Rwanda, Butare, Rwanda. 114 pp.

Habineza, C. 1986. Analyse de l'effet de la fumure organique (Fientes de poules) sur la croissance du *Tilapia nilotica*. (The influence of chicken manure on the growth of *Tilapia nilotica* in Rwandan fish ponds.) Thesis for the degree of Ingenieur Agronome, Université Nationale du Rwanda, Butare, Rwanda.

Hakuziyaremye, E. Etude des effets de l'alimentation sur la croissance des tilapias: Essais en bacs sur *T. macrochir* et *T. rendalli*. (A study of the effects of feeding on the growth of tilapias: Tank studies with *T. macrochir* and *T. rendalli*.) Thesis for the degree of Ingenieur Agronome, Université Nationale du Rwanda, Butare, Rwanda. 132 pp.

Hanson, B., and F. Rwangano. Natural productivity of pond systems in Rwanda.

Harwanimbaga, C. 1987. A preliminary study of the plankton population in fish ponds at Rwasave (Butare, Rwanda). Thesis for the degree of Licensie en Sciences, Université Nationale du Rwanda, Butare, Rwanda.

Hatangimbabazi, J. D. 1989. Description des communautés planctonigues des différents habitats de quelques étangs piscicoles de Rwasave (Butare). (Study of the plankton communities of different habitats in fish ponds.) Thesis for the degree of Licencié en Biologie Animale, Université National du Rwanda, Butare, Rwanda. 93 pp.

Isangu M.-M. 1989. L'association porce-poissons en station: étude de rentabilité financiére. (Integrated pig-fish culture: an economic analysis.) Thesis for the degree of Ingénieur Agronome, Université Nationale du Rwanda, Butare, Rwanda. 107 pp.

Kakuze, A. 1989. Contribution á létude du régime alimentaire de *Tilapai nilotica* (L. 1758) des étangs fertilisés de Rwasave (Butare). (A preliminary study of the feeding habits of *Tilapia nilotica* in fertilized ponds at Rwasave (Butare)). Thesis for the degree of Licensié en Biologie Animale, Université Nationale du Rwanda, Butare, Rwanda. 93 pp.

Murwanashyaka, J.N. 1989. Study of the food of *Clarias gariepinus* of Lake Iheme. B.S. thesis, Université Nationale du Rwanda, Butare, Rwanda. 116 pp.

Murwanashyaka, J.N. 1989. Alimentation et parasitismo de Clarias gariepinus (Burchell, 1822) au Loc Ihema: impact de sa predation sur l'évolution du stock en hapiochromis. (Feeding habits and parisitism in Clarias gariepinus (Burchell, 1822) in Lake Ihema: impact of its predation on haplochromis stocks.) Thesis for the degree of Ingénieur Agronome, Université Nationale du Rwanda, Butare, Rwanda. 101 pp.

Ndisebuye, A. 1986. Etude des conditions de reproduction de *Tilapia nilotica* en etangs de pisciculture. (A study of conditions affecting the reproduction of *Tilapia nilotica* in Rwandan fish ponds.) Thesis for the degree of Ingénieur Agronome, Université Nationale du Rwanda, Butare, Rwanda.

Ngarambe, O. 1986. Etude de l'influence de la fumure organique (fientes de poules) sur la dynamique des elements fertilisants de l'eau et du sol de quelques étangs piscicoles de Rwasave. (The influence of chicken manure on soil and water fertility in several fish ponds at Rwasave.) Thesis for the degree of Ingenieur Agronomie, Université Nationale du Rwanda, Butare, Rwanda. 105 pp.

Nsengiyumva, V. 1989. Production des alevins monosexes de Tilapia nilotica Linnaeus par la méthode du sex-reversal. (Production of *Tilapia nilotica* fingerlings by sex reversal methods.) Thesis for the degree of Ingénieur Agronome, Université Nationale du Rwanda, Butare, Rwanda. 107 pp.

Rwangano, F. 1990. Interactions of input types and water quality on the production of *Orechromis niloticus* (L.) in Rwandan Ponds. M.S. thesis, Oregon State University, Corvallis, U.S.A. 99 pp.

Uwera, M.J. 1987. Une étude des modalités d'échantillonage des poissons en etangs piscicoles. (A comparative study of methods for sampling fish in ponds.) Thesis for the degree of Ingenieur Agronomie, Université Nationale du Rwanda, Butare, Rwanda.

Publications and Reports

Hanson, B.J., J.F. Moehl, K.L. Veverica, F. Rwangano, and M. Van Speybroeck. 1988. Pond culture of tilapia in Rwanda, a high altitude equatorial African country. Pages 553-559 *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, 623 pp. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Hishamunda, N., and J.E. Moehl. 1989. Rwanda National Fish Culture Project. Inter. Cent. for Aquaculture R and D Series No. 34, Auburn University, Alabama.

Moehl, J.F., Jr., K.L. Veverica, B.J. Hanson, and N. Hishamunda. 1987. Development of appropriate pond management techniques for use by Rwandan farmers. International Symposium on Tilapia in Aquaculture, Bangkok, Thailand.

Scientific Papers Presented

Curtis, L., F. Diren, M. Hurley, and R. Tubb. 1988. Minimal residue levels after sex reversal of *Tilapia nilotica* by methyltestosterone but persistent alterations in hepatic detoxication systems. Federation of American Societies for Experimental Biology, Las Vegas, Nevada (April).

Hanson, B., V. Ndoreyaho, F. Rwangano, E. Rurangwa, M. Van Speybroeck, R. Tubb, and W. Seim. 1988. Relationship between water chemistry and the growth of *Tilapia nilotica* in Rwandan (Central Africa) fish ponds fertilized with chicken manure. World Aquaculture Society Meeting, Honolulu, Hawaii (January).

Harwanimbaga, C., F. Rwangano, and B. Hanson. 1988. A descriptive study of plankton in Rwandan (Central Africa) fish ponds fertilized with chicken manure or triple superphosphate. World Aquaculture Society Meeting, Honolulu, Hawaii (January).

Rwangano, F., M. Van Speybroeck, E. Rurangwa, K. Veverica, and B. Hanson. 1988. Fingerling production of *Tilapia nilotica* at the Rwasave Fish Culture Station of the National University of Rwanda. World Aquaculture Society Meeting, Honolulu, Hawaii (January).

Sikoki, F., L. Curtis, and R. Tubb. 1986. Inhibition of hepatic UDP-Glucuronyl transferase (UDP-GT) activity coincident with elevated plasma sex steroid concentrations during gonadal maturation in carp. Society of Toxicologists, Atlanta, Georgia.

Tubb, R. 1986. The reduction of estradiol by liver enzymes in carp and rainbow trout. Toxicology Meetings, New Orleans (March).

Manuscripts

Curtis, L.R., F.T. Diren, M.D. Hurley, W.K. Seim, and R.A. Tubb. 1990. Disposition and elimination of 17α-methyltestosterone in Nile Tilapia (*Oreochromis niloticus*). Oregon State University Agricultural Experiment Station Technical Paper No. 9333. Oregon State University, Corvallis.

Hanson, B.J., L.R. Curtis, F.T. Diren, M.D. Hurley, W.K. Seim, and R.A. Tubb. 1990. Disposition and elimination of 17α-methyltestosterone in Nile tilapia (*Orechromis niloticus*). Submitted to Aquaculture.

Lin, C.K. 1986. Biological principles of pond culture: phytoplankton and macrophytes. Pages 21-26 *in* James E. Lannan, R.O. Smitherman and George Tchobanoglous, editors. Principles and Practices of Pond Aquaculture: A State of the Art Review. Oregon State University Press, Corvallis. Originally published as internal report in 1983.

Moehl, J.F., Jr., K.L. Veverica, B.J. Hanson, and N. Hishamunda. Development of appropriate pond management techniques for use by rural Rwandan farmers. Submitted to the Second International Symposium on Tilapia in Aquaculture.

Sikoki, F.D., R.A. Tubb, and L.R. Curtis. 1986. Inhibition of hepatic UDP-glucuronyl transferase (UDP-GT) activity coincident with elevated plasma sex steroid concentrations during gonadal maturation in carp. Pages 553-559 *in* R.S.V. Pullin, T. Bhukaswan, The Toxicologist, v.6(1).

UNIVERSITY OF HAWAII/HONDURAS

Manuscripts

Hopkins, Kevin. Reporting fish growth, a review of the basics. Submitted to World Aquaculture. Under review.

Hopkins, K., and A. Yakupitiyage. Bias in seine sampling of tilapia. Submitted to Journal of the World Aquaculture Society. Under review.

Hopkins, K., and A. Yakupitiyage. Bias in seine sampling of tilapia. Submitted to Journal of the World Aquaculture Society. Under review.

Szyper, J.P., K. Hopkins, and C.K. Lin. Production of *Oreochromis nilotica* (L.) and ecosystem dynamics in manured ponds of three depths. Submitted to Aquaculture and Fisheries Management. Under review.

UNIVERSITY OF HAWAII/THE PHILIPPINES

Theses

Pahila, I.G. 1986. Sorbed and soil solution phosphorus in relation to the optimum phosphorus level of lablab in some brackishwater ponds. M.S. thesis, Department of Fisheries, University of the Philippines in the Visayas.

Publications and Reports

Corre, V.L., Carpenter, E.J. Pudadera, and R.D. Fortes. 1986. The effects of feeds and fertilizer on the production of *Oreochromis niloticus* in brackishwater ponds. Unpublished paper. University of Hawaii and University of the Philippines in the Visayas.

Fast, A.W., K.E. Carpenter, V.L. Corre, and R.L. Janeo. 1986. The effects of water depth and circulation on the productivity of *Penaeus monodon* and water quality in earthen ponds. Unpublished paper. University of Hawaii and University of the Philippines in the Visayas.

Fast, A.W., K.E. Carpenter, V.L. Corre, and R.L. Janeo. 1986. Water quality management in brackishwater shrimp ponds using bivalves and fish. Unpublished paper. University of Hawaii and University of the Philippines in the Visayas.

Olin, P., D. Barclay, and A.W. Fast. In preparation. Induced spawning and larval rearing of the Chinese catfish *Clarius fuscus* in Hawaii.

Scientific Papers Presented

Carpenter, K.E., A.W. Fast, R.D. Fortes, V.L. Corre, Jr., J. Woessner, and R.L. Janeo. 1986. The effects of water depth and circulation on the growth of *Penaeus monodon* in semi-intensive culture in earthen ponds. Presented to the Asian Fisheries Forum Meeting, Manila (May).

Chiu, Y., V. Estilo, and K.E. Carpenter. Effects of water exchange rates on nutrient levels and productivity of brackishwater fish ponds.

Chiu, Y., M.P. Macahilig, and M.A. Sastrillo. 1986. Factors affecting the feeding rhythm of milkfish (*Chanos chanos* Forsskal). Proceedings of the Asian Fisheries Forum Meeting, Manila (May).

Fast, A.W., K.E. Carpenter, F.J. Estilo, and H.J. Gonzales. 1987. Effects of water depth on dynamics of Philippines brackishwater shrimp ponds. Presented at the World Aquaculture Society Meeting, Ecuador (January).

Fortes, R.D., V.L. Corre, and E.J. Pudadera. 1986. The effects of fertilizers and feeds as nutrient sources in the production of *Oreochromis niloticus* in Philippines brackishwater ponds. Presented to the Asian Fisheries Forum Meeting, Manila (May). (CRSP 86:2)

Minsalan, C.L., and Y.N. Chiu. 1986. Studies on the use of teaseed cake for the selective elimination of finfishes in shrimp ponds. Presented to the Asian Fisheries Forum Meeting, Manila (May).

Sanares, R.C., S.A. Katase, A.W. Fast, and K.E. Carpenter. 1986. Water quality dynamics in brackishwater shrimp ponds with artificial aeration and circulation. Presented to the Asian Fisheries Forum Meeting, Manila (May).

Ver, L.M., and Y.N. Chiu. 1986. The effects of paddlewheel aerators on ammonia and carbon dioxide removal in intensive pond culture. Presented to the Asian Fisheries Forum Meeting, Manila (May).

Manuscripts

Fast, A.W. 1986. Pond production systems: Water quality management practices. Pages 141-168 *in* James E. Lannan, R.O. Smitherman, and George Tchobanoglous, editors. Principles and Practices of Pond Aquaculture: A State of the Art Review. Oregon State University Press, Corvallis. (Originally published internally in 1983.)

UNIVERSITY OF HAWAII AT HILO/THAILAND

Publications and Reports

Hopkins, K.D., M.L. Hopkins, and D. Pauly. 1988. A multivariate model of tilapia growth, applied to seawater tilapia culture in Kuwait. Pages 29-39 *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, International Center for Living Aquatic Resources Management, Manila, Philippines.

Hopkins, K.D. 1988. Reporting fishpond yields to farmers. Aquabyte 1(2):6.

Szyper, J., and C.K. Lin. 1990. Techniques for assessment of stratification and effects of mechanical mixing in tropical fish ponds. Aquacultural Engineering (in press).

UNIVERSITY OF MICHIGAN/THAILAND

Theses

Boonsong S. Role of zooplankton in feeding juvnile tilapia (*Oreochromis niloticus*). M.S. thesis.

Narong V. Effects of phytoplankton on nursing walking catfish fry in static and flow-through water systems.

Suresh, A. V. Influence of stocking density on red tilapia production in a recirculation system.

Publications and Reports

Diana, J.S., and A. Fast. 1989. The effects of water exchange rate and density on yield of the walking catfish, *Clarias fuscus*. Aquaculture 78:267-276.

Diana, J.S., and D. Ottey. 1986. Biological principles of pond culture: fish. Pages 39-52 *in* James E. Lannan, R.O. Smitherman and George Tchobanoglous, editors. Principles and Practices of Pond Aquaculture: A State of the Art Review. Oregon State University Press, Corvallis. Originally published as internal report in 1983.

Diana, J.S., S.L. Kohler, and D.R. Ottey. 1988. A yield model for walking catfish production in aquaculture systems. Aquaculture 71:23-35.

Diana, J.S., P.J. Schneeberger, and C.K. Lin. 1988. Relationships between primary production and yield of *Tilapia nilotica* in ponds. Pages 1-6 *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. Manila, Philippines.

Lin, C. K. 1986. Acidification and reclamation of acid sulfate soil fishponds in Thailand. Pages 71-74 *in* J. L. MacLean, L. B. Dizon, and L. V. Hosillos, editors. The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Lin, C. K. 1986. Nutrient dynamics between inorganic and organic fertiliztaion in Tilapia culture ponds. Proceedings of the 24th Kasetsart University Conference on Fisheries 174-182.

Lin, C.K. 1986. Biological principles of pond culture: phytoplankton and macrophytes. Pages 21-26 *in* James E. Lannan, R.O. Smitherman and George Tchobanoglous, editors. Principles and Practices of Pond Aquaculture: A State of the Art Review. Oregon State University Press, Corvallis. (Originally published internally in 1983.)

Lin, C. K. 1989. Prawn culture in Taiwan: what went wrong? World Aquaculture 20: 19-20.

Lin, C. K. 1989. Occurrence of mass mortality of black tiger prawns in Taiwan. Thai Fisheries Gazette 42:209-216.

Lin, C.K., and M. Boonyaratpalin. 1988. An analysis of biological characteristics of *Macrobrachium rosenbergii* in relation to pond production and marketing in Thailand. Aquaculture 74:205-215.

Lin, C.K., C. Apinhapath, and V. Tansakul. 1988. Biological nitrogen fixation as a source of nitrogen input in fishponds. Pages 53-58 *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. Manila, Philippines.

McNabb, C.D., and eight coauthors. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. Pages 169-172 *in* R. Hirano and I. Hanyu, editors. Proceedings of The Second Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Nash, G., S. Chinabut, and C. Limsuwan. 1987. Idiopathic muscle necrosis in the freshwater prawn, *Macrobrachium rosenbergii* de Man, cultured in Thailand. Journal of Fish Diseases 10:109-120.

Tansakul, V., T. Sae-Lee, and E. Sae-Loaw. 1987. Acute toxicity and treatment effect of formalin to early larvae prawn, *Macrobrachium rosenbergii* (de Man). Proceedings of the 25th Kasetsart University Conference on Fisheries, 1-11.

Tavarutmanegul, P., and C.K. Lin. 1987. Breeding and rearing of sand goby (*Oxyeleotris rosenbergii*, Blk.) fry. Aquaculture 69:299-305.

Lin, C.K. 1990. Integrated culture of walking catfish and tilapia. Pages 209-212 *in* R. Hirano and I. Hanyu, editors. Proceedings of 2nd Asian Fisheries Forum. Asian Fisheries Society, Manila.

<u>Invited Seminars</u>

Lin, C. K. 1989. Intensive pond culture of freshwater prawns and marine shrimps in Thailand. Auburn University, Auburn, Alabama (23 May).

Lin, C. K. 1989. The problems of marine shrimp culture in Taiwan. Royal Thai Government Department of Fisheries and Shrimp Farmers Association. Bangkok (July).

Lin, C. K. 1989. Overview of current aquaculture in the Orient and the USA. United States Agency for International Development, Bangkok (28 July).

Lin, C. K. 1989. Aquaculture in Thailand and AIT's Program. Citizens Ambassadors, Bangkok (August).

Lin, C. K. 1990. Effects of intensive shrimp culture on coastal environment in upper Gulf of Thailand. Royal Thai Government Department of Fisheries and Shrimp Farmers Association (15-16 February).

Lin, C. K. 1990. Current status of freshwater prawn and marine shrimp culture in Thailand, Great Lakes Fisheries Research Laboratory, Ann Arbor, Michigan.

<u>Scientific Papers Presented</u>

Diana, J.S., and C.K. Lin. 1988. Effects of fertilization rate on primary production and yield of tilapia in ponds. World Aquaculture Society, Honolulu, Hawaii (January).

Diana, J.S., C.K. Lin, and D. Dettweiler. 1989 Cascading trophic interactions: a test of the hypothesis using tilapia culture data. World Aquaculture Society, Los Angeles, California (February).

Diana, J.S., P.J. Schneeberger, and C.K. Lin. 1987. Relationships among nutrient input, primary production, and yield of *Tilapia nilotica* in ponds. Second International Symposium on Tilapia in Aquaculture, Bangkok, Thailand.

Lin, C. K. 1990. Integrated culture of walking catfish and tilapia. Second Asian Fisheries Forum. Tokyo (20 April).

Lin, C.K., and S. Auworatham. 1987. Effects of inorganic and organic fertilizers on zooplankton production in tilapia ponds. 25th Kasetsart University Conference, Bangkok, Thailand.

Lin, C.K., and J.S. Diana. 1987. Fertilization effects on pond carrying capacity in extensive culture of tilapia (*Oreochromis niloticus*). Second International Symposium on Tilapia in Aquaculture, Bangkok.

Lin, C.K., and J.S. Diana. 1989. Integrated culture of walking catfish and tilapia in earthern ponds. World Aquaculture Society, Los Angeles, California (February).

Lin, C. K., and J. Szyper. 1990. Stratification of temperature and dissolved oxygen in tropical fish ponds. World Aqaculture '90. Halifax, (10 June).

Lin, C.K., A. Apinapat, and V. Tansakul. 1987. Biological nitrogen fixation as a source of nitrogen input in fish ponds. Second International Symposium on Tilapia in Aquaculture, Bangkok, Thailand.

Lin, C.K., S. Auworatham, and V. Tansakul. 1986. Dietary consumption of zooplankton by tilapia in fertilized ponds. Thai Fisheries Academy Seminar.

Lin, C.K., M. Boonyarapalin, and Y. Musig. 1986. Biological characteristics of *Macrobrachium rosenbergii* (de Man) in relation to pond production and marketing. First Asian Fisheries Society Forum, Manila, Philippines.

Lin, C.K., E. Sae-Loaw, and V. Tansakul. 1987. Rearing post-larvae of *Macrobrachium rosenbergii* at high stocking density in concrete tanks. 25th Kasetsart University Conference, Bangkok.

Lin, C.K., V. Tansakul, W. Muthuwana, and S. Auworatham. 1986. Production and utilization of organic carbon in Tilapia culture and ponds. Thai Fisheries Academy Seminar.

Lin, C.K., W. Muthuwana, V. Tansakul, S. Auworatham, and C. Apinapat. 1986. Nutrient dynamics between inorganic and organic fertilized ponds for tilapia culture. Thai Fisheries Academy Seminar.

Musig, Y., M. Boonyarapalin, and C.K. Lin. 1987. Water quality in Macrobrachium grow-out ponds. 25th Kasetsart University Conference, Bangkok.

Tansakul, V., T. Sae-Lee, and E. Sae-Loaw. 1987. Acute toxicity and treatment effect of formalin on early larval prawns (*Macrobrachium rosenbergii* de Man). 25th Kasetsart University Conference, Bangkok.

<u>Manuscripts</u>

Diana, J. S., D. J. Dettweiler, and C. K. Lin. 1990. Effect of tilapia *Oreochromis niloticus* on the ecosystem of aquaculture ponds, and its significance to the trophic cascade hypothesis. Can. J. Fish. Aquat. Sci. (in press).

Diana, J., C. K. Lin, P. Schneeburger. 1990. Relationships between primary production and yield of tilapia in ponds. Aquaculture (in press).

Diana, J., C. K. Lin, P. Schneeburger. 1990. Relationships among nutrient inputs, nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. Aquaculture (in press).

Lin, C.K. 1988. An analysis of biological characteristics of *Macrobrachium rosenbergii* in relation to pond production and marketing. Accepted by Aquaculture.

Lin, C. K. 1990. Production and consumption of freshwater prawns (*Macrobrachium rosenbergii*) – the Thai way (in review).

Lin, C.K., and P. Tavarutmaneegul. 1986. Acidification and reclamation of acid-sulfate soil fish ponds in Thailand. First Asian Fisheries Society Forum, Manila, Philippines. Published in Forum proceedings.

Lin, C. K., K. Jaiyen, V. Muthuwana. 1990. Integrated culture of intensive and semi-intensive aquaculture: concept and example. Thai Fisheries Gazette (in review).

Muthuwana W., V. Tansakul, and C.K. Lin. 1986. Nutrient dynamics between inorganic and organic fertilized ponds for Tilapia culture. Proceedings of the Kasetsart University Agricultural Conference (January 1985).

Muthuwana W., V. Tansakul, and C.K. Lin. 1986. Production and utilization of organic carbon in tilapia culture ponds. Proceedings of the Kasetsart University Agricultural Conference (January 1985).

Szyper, J. P., and C. K. Lin. 1990. Stratification of temperature and dissolved oxygen in mixed and unmixed ponds. Journal Aquaculture Engineering (in press).

DATA ANALYSIS AND SYNTHESIS TEAM

Theses

Giovannini, P. 1989. Analysis and modeling of dissolved oxygen concentrations and photosynthesis in warm water aquaculture ponds. M.S. thesis. 133 pp.

Publications and Reports

Chang, William. 1989. Integrated lake farming to manage fish and environment in the large shallow lakes in China. In press. Aquaculture and Fisheries Management.

Chang, William. 1989. Estimates of hypolimnetic oxygen deficits in ponds. Aquaculture and Fisheries Management 20:163:172.

Chang, W., and H. Ouyang. 1988. Dynamics of dissolved oxygen and vertical circulation in fish ponds. Aquaculture 74:263-276.

Fridley, R. B., R. H. Piedrahita, and T.M. Losordo. 1988. Challenges in aquacultural engineering. Agricultural Engineering 69(4):12-15.

Giovannini, P., and R.H. Piedrahita. 1988. Analysis and modeling of dissolved oxygen in warm water aquaculture ponds. American Society of Agricultural Engineers Paper Number 88-5004.

Giovannini, P., and R.H. Piedrahita. 1989. Analysis and modeling of diel pond dynamics. American Society of Agricultural Engineers Paper Number 88-5004.

Giovannini, P., and R.H. Piedrahita. 1990. Measuring primary production efficiency in aquacultural ponds. American Society of Agricultural Engineers Paper Number 90-7034.

Grace, G., and R. H. Piedrahita. 1989. Carbon dioxide removal in packed column aerators. American Society of Agricultural Engineers Paper Number 89-7011.

Lannan, J.E. 1990. Farming and ranching an aquatic system. Food Reviews International, 6:293-298.

Lannan, J.E., G.A.E. Gall, J.E. Thorpe, C.E. Nash, and B.A. Ballachey. 1989. Genetic resource management of fish. Genome 31:798-804.

Losordo, T.M., and R.H. Piedrahita. 1990. Modelling temperature variation and thermal stratification in shallow aquaculture ponds. Ecological Modeling (In press).

Piedrahita, R.H. 1988. Introduction to computer modeling of aquaculture pond ecosystems. Aquaculture and Fisheries Management 19:1-12.

Piedrahita, R.H. 1989. Simulation of short-term management actions to prevent oxygen depletion in ponds. American Society of Agricultural Engineers Paper Number 89-7555.

Piedrahita, R.H. 1990. Aquaculture: engineering and construction. *In* Y.H. Hui, editor. Wiley Encyclopedia of Food Science and Technology. Wiley and Sons, New York (in press).

Piedrahita, R.H. 1990. Detritus based aquaculture systems. Food Reviews International 6(3):317-331.

Piedrahita, R.H. 1990. Calibration and validation of TAP, an aquaculture pond water quality model. Aquacultural Engineering (in press).

Piedrahita, R.H., and D.E. Brune. 1989. Aquacultural engineering: aquatic habitat commands innovative thrusts. Agricultural Engineering 70(1):30-32.

Piedrahita, R.H., and J.K. Wang. 1988. Engineering in aquaculture, an overview. *In* Proceedings of the Joint U.S. India International Symposium on Aquaculture Research Needs for the Year 2000. New Delhi, India (in press).

Scientific Papers Presented

Piedrahita, R.H. 1989. Engineering aspects of warmwater hatchery design. Presented at Workshop on Milkfish Fry Production Technology, Bali, Indonesia. Oceanic Institute, Hawaii.

Piedrahita, R.H., and G. Grace. 1990. Removal of carbon dioxide and intensive aquaculture systems. Presented at the Annual Meeting of the World Aquaculture Society, Halifax, Nova Scotia (June).

Whitman, M. H., and R. H. Piedrahita. 1989. Water quality requirements of Pacific oysters (*Crassostrea gigas*) in holding systems. Presented at the Annual Meeting of the World Aquaculture Society. Los Angeles. February. 12 pp.

Manuscripts

Chang, William. 1989. Integrated lake farming to manage fish and environment in the large shallow lakes in China. Aquaculture and Fisheries Management (in press).

Giovannini, P., and R.H. Piedrahita. 1989. Analysis and modeling of diel pond dynamics. American Society of American Engineers Paper Number 89-7556 (submitted)

Piedrahita, R.H. 1989. Modeling water quality in aquaculture ecosystems. *In* D.E. Brune and J.R. Tamasso, editors. Aquaculture and Water Quality. World Aquaculture Society. Baton Rouge, Louisiana (in press).

Piedrahita, R.H. 1990. Calibration and validation of TAP, an aquaculture pond water quality model. Aquacultural Engineering (in press).

Springborn, R. R., A. L. Jensen, and W. Y. B. Chang. Application of the initial value solution of Von Bertalanffy's solution to *Tilapia nilotica* growth in aquaculture experiment. Aquaculture (submitted).

Springborn, R. R., A. L. Jensen, and W. Y. B. Chang. A multivariate approach for examining *Tilapia nilotica* growth in aquaculture experiment using Von Bertalanffy's growth solution (submitted).

OTHER PUBLICATIONS BY CRSP RESEARCHERS

Publications

Brune, D.E., and R.H. Piedrahita. 1982. Operation of a retained biomass nitrification system for treating aquaculture water for reuse. Proceedings of the First International Conference on Fixed-Film Biological Processes, pp. 845-869.

Chang, W. Submitted. Integrated lake farming to manage fish and environment in large shallow lakes in China. Fisheries.

Chang, W. 1986. Aquaculture research in China. China Exchange News, CSCPRC, National Academy of Sciences 14(2):13-16.

Chang, W. 1986. Practical methods for treating fish during oxygen stress in ponds. Aquaculture Magazine 13(4):20-22.

Chang, W. 1987. Fish culture in China. Fisheries 12(3):11-15.

Chang, W. 1987. Historical center of fish center in China in Lake Tai/Yangtze River Delta. Aquaculture Magazine 13:39-42.

Chang, W. 1987. Large lakes of China. J. Great Lakes Res. 13(3):235-249.

Chang, W., and R. Rossmann. Changes in the abundance of blue-green algae related to nutrient loadings in the nearshore of Lake Michigan. Hydrobiologia, 157:271-278.

Chang, W., J. Diana, and W. Chapoehuk. 1983. Strengthening of Southeast Asian Aquaculture Institutions. Workshop Report to Agency for International Development.

Ebeling, J.M., and R.H. Piedrahita. 1985. Microcomputer-based data acquisition system for aquaculture use. American Society of Agriculture Engineers Paper Number 85-5014. 8 pp.

Fridley, R.B., R. H. Piedrahita, and T.M. Losordo. 1988. Challenges in aquacultural engineering. Agricultural Engineering 69(4):12-15.

Grace, G., and R.H. Piedrahita. 1989. Carbon dioxide removal in packed column aerators. American Society of Agricultural Engineers Paper Number 89-7011.

Hopkins, K.D., J.E. Lannan, and J.R. Bowman. 1988. Managing a database for pond research data - the CRSP experience. Aquabyte 1(1).

Losordo, T.M., and R.H. Piedrahita. 1988. Simulating aquacultural pond thermal stratification with a spreadsheet model. American Society of Agricultural Engineers Paper Number 88-5003.

Losordo, T.M., and R.H. Piedrahita. 1988. Modeling vertical water quality profiles in aquaculture ponds, review and evaluation. Pages 313-327 *in* Proceedings of the Conference Aquacultural Engineering: Technologies for the future, Stirling, Scotland. I. Cheme Symposium Series No. 111, EFCE Publications Series No. 66, Rubgy, United Kingdom.

Losordo, T.M., J.M. Ebeling, and R.H. Piedrahita. 1986. Stratification measurement techniques in aquaculture ponds. American Society of Agricultural Engineers Paper Number 86-5047. 14 pp.

Losordo, T.M., R.H. Piedrahita, and J.M. Ebeling. 1988. An automated water quality acquisition system for use in aquaculture ponds. Aquacultural Engineering 7:265-278

Piedrahita, R.H. 1987. Sensitivity analysis for an aquacultural pond model. Pages 119-123 *in* J.G. Balchen, editor. Automation and Data Processing in Aquaculture, Pergamon Press, New York.

Piedrahita, R.H. 1988. Introduction to computer modeling of aquaculture pond ecosystems. Aquaculture and Fisheries Management 19:1-12.

Piedrahita, R.H., and D.E. Brune. 1989. Aquacultural Engineering: Aquatic habitat commands innovative thrusts. Agricultural Engineering 70(1):30-32.

Piedrahita, R.H., and G. Tchobanoglous. 1987. The use of human wastes and sewage in aquaculture. Pages 336-352 *in* D.J.W. Moriarty and R.S.F. Pullin, editors. Detritus and microbial ecology in aquaculture. ICLARM Conference Proceedings 14, 420 pp. International Center for Living Aquatic Resources Management, Manila, Philippines.

Piedrahita, R.H., J.M. Ebeling, and T.M. Losordo. 1987. Use of data acquisition systems in aquaculture. Pages 259-262 *in* J.G. Balchen, editor. Automation and Data Processing in Aquaculture, Pergamon Press, New York.

Piedrahita, R.H., G. Tchobanoglous, and B. Moore. 1987. Effect of organic matter addition to fish culture systems. Transactions of ASAE. 30(1):233-237.

Piedrahita, R.H., D.E. Brune, G. Tchobanoglous, and G.T. Orlob. 1984. General model of the aquaculture pond ecosystem. J. World Mariculture Soc. 15:355-366.

Popma, T.J., and B.W. Green. 1990. Aquaculture Production Manual: sex reversal of tilapia in earthern ponds. Res. and Dev. Series. International Center for Aquaculture, Auburn University, Alabama.

Sikoki, F.D., R.A. Tubb, and L.R. Curtis. 1989. Elevation of sex steroids and inhibition of UDP - glucuronyl transferase are out of phase during gonadal maturation in the common carp. Comp. Biochem. Physiol. 92C:2:267-272.

Smith, D.W., and R.H. Piedrahita. 1988. The relation between phytoplankton and dissolved oxygen concentration in fish ponds. Aquaculture 68:249-265.

Teichert-Coddington, D.R., and R.O. Smitherman. 1988. Lack of response by *Tilapia nilotica* to mass selection for rapid early growth. Trans. Amer. Fish. Soc. 117:297-300.

Teichert-Coddington, D.R., L.L. Behrends, and R.O. Smitherman. 1990. Effects of manuring regime and stocking rate on primary production and yield of tilapia using liquid swine manure. Aquaculture 88:61-68.

<u>Scientific Papers Presented</u>

Chang, W. 1986. Large lakes in China. Abstract. 29th Great Lakes Res.

Chang, W. 1986. Vertical oxygen dynamics of shallow tropical impoundments in the Pearl River Delta, China. Tran. Amer. Phys. Union 66(51):13-1.

Chang, W. 1987. China integrated aquaculture: an efficient ecological system. Abstract, The Limnol. & Oceanogr. 1987 Annual Meeting.

Chang, W. 1987. The world's highest lake: Tibetan Lakes. Abstract. 30th Great Lakes Res.

Whitman, M.H., and R.H. Piedrahita. 1989. Water quality requirements of Pacific oysters (*Crassostrea gigas*) in holding systems. Presented at the Annual Meeting of the World Aquaculture Society, Los Angeles, February. 12 pp.

Appendix B. List of Acronyms

AID - Agency for International Development

AIT - Asian Institute of Technology, Thailand

AU - Auburn University

Baseline Data - that information and data base in some sector or aspect of a developing country which is necessary to measure change in the future

BFAR - Board for Food and Agriculture Research

BIFAD - Board for International Food and Agricultural Development

Bilateral Programs- U.S. assistance programs involving arrangements between a single developing country and a single donor country

BOA - Basic Ordering Agreement

BOD (Board of Directors) - an advisory body selected to assist, advise, and make policy recommendations to the ME in the execution of a CRSP; members represent the interests of the CRSP

CGIAR - Consultative Group on International Agricultural Research

CIFAD - Consortium for International Fisheries and Aquaculture Development

CIFRAI - Council for Fisheries Research and Assistance Institutions

Collaborating Institutions - institutions which form a partnership arrangement with a lead participating U.S. institution to collaborate on a specific research project

CRSP - Collaborative Research Support Program

CUL - Catholic University of Leuven, Belgium

DAST - Data Analysis and Synthesis Team

Data Analysis and Synthesis - the process of compiling and analyzing information about pond culture systems from diverse sources into a coherent, usable format that can be applied to the development of predictive models and to the improvement of the efficiency of these systems

EEP - External Evaluation Panel - senior scientists not involved in the CRSP and selected externally for their ability to evaluate objectively the scientific progress and relevance of a CRSP program on an ongoing basis

EOP - Equal Opportunity Programs

Experimental Protocol - a detailed plan of a field experiment which specifies experimental methods, sampling schedules, data collection, etc.

Experimental Treatment - fish cultural practices (e.g., fertilizer application, supplemental feeding, etc.) which modify the physical, chemical, and biological environment

Expert System - a computerized compilation of knowledge that is used to make "intelligent" decisions about the management or status of a process or system

Field Experiments - controlled fish production experiments in which quantitative responses to different levels of treatments are measured

FTE - Full Time Equivalent

Global Experiment - the overall plan of a CRSP for research on problems and constraints, global in nature, whose results are applicable and transferable regionally and globally (worldwide)

Grant Agreement - the formal legal document which represents a binding agreement between AID and the ME institution for a CRSP; this is the legal document for the CRSP recognized as such by AID and the recipient institutions

Grant Proposal - the formal document submitted by an ME to AID, proposing a CRSP for receiving a grant outlining the manner of implementation of the program, and showing the budgetary requirements

Host Country (HC) - a developing country in which a CRSP has formal activities

ICA - International Center for Aquaculture

ICLARM - International Center for Living Aquatic Resources Management

IDRC - International Development Resource Centre

Institutional Development - improvement in the capability of institutions in developing countries to conduct development programs for agriculture and other sectors, or for implementing educational/training, research, health, and other public programs; improvements may include physical facilities, equipment, furnishing, transportation, organization, but refers primarily to development and training of professional cadre

IPA - Inter-governmental Personnel Act

JCARD - Joint Committee on Agricultural Research and Development (formerly Joint Research Committee), BIFAD

JRC - Joint Research Council, USAID

LDC - Lesser Developed Countries

Matching Requirement Document - that sum of resources, financial or in-kind, which participating U.S. institutions must collectively contribute to a CRSP program as defined in the grant (also called "cost sharing")

ME - Management Entity

Mission - a formally organized USAID unit in a developing country led by a Mission Director or a country representative

MOU - Memorandum of Understanding

MSU - Michigan State University

NCRAC - North Central Regional Aquaculture Center

NIFI - National Inland Fisheries Institute, Thailand

NMFS - National Marine Fisheries Service

OIRD - Office of International Research and Development

OSU - Oregon State University

Participating Institutions - those institutions that participate in the CRSP under a formal agreement with the Management Entity which receives the AID grant

PD/A CRSP - Pond Dynamics/Aquaculture Collaborative Research Support Program

PI - Principal Investigators - scientists in charge of the research for a defined segment or a scientific discipline of a CRSP

PMO - Program Management Office

Practices - fish cultural activities related to design, management, and operation of pond culture systems

Predictive Models - mathematical models used to simulate the process occurring in pondsystems; in the context of this CRSP, predictive models are used as analytical and management tools to improve the efficiency of pond systems

Principles - the physical, chemical, and biological processes occurring in pond systems and their interactions

RENARE - Department of Renewable Natural Resources, Honduras

S&T Bureau (S&T/AGR) - Bureau of Science and Technology, a central bureau of AID in Washington, charged with administering worldwide technical and research programs for the benefit of USAID-assisted countries

Subgrant Agreement - a document representing a subagreement made between the ME and a participating institution under authority of the grant

Appendix C. Excerpts from the CRSP Fifth Work Plan

REQUIRED MEASUREMENTS

This section of the work plan lists the minimum requirements for data collection by the CRSP projects. The accepted methods for data collection are presented in the Summary of Accepted Analytical Methods (Section 3), which starts on page 44. Detailed descriptions of accepted methods are contained in the appendices. Frequencies of data collection as specified in this section are minimum frequencies. Data may be collected more frequently at the discretion of the individual projects.

The following measurements must be taken daily:

- Solar Radiation
- Wind Speed
- Air Temperature (maximum and minimum)
- Rainfall
- Evaporation
- Mortalities
- Pond Depth
- Water Inflow and Overflow

There will be at least three intensive sampling periods for each experiment: (1) during the second week; (2) midway through the experiment; and (3) during the final week. Whole column samples collected at mid-morning should be used unless specified otherwise. The variables to be observed are:

- Total Kjeldahl Nitrogen
- Ammonia Nitrogen
- Total Phosphorous
- Secchi Disk Visibility
- Chlorophyll *a*
- Dark Bottle Respiration
- Total Suspended Solids
- Total Volatile Solids
- Total Alkalinity (3 depths: top, middle, bottom)
- Primary Productivity

Diel studies will be conducted simultaneously with the intensive sampling measurements in order to measure spatial and temporal fluctuations within a pond. Samples for diel studies will be collected at dawn, 1000, 1400, 1600, 1800, and 2300 hours, and at dawn the next day at a minimum of two depths, but preferably at three depths. The exact time of sample collection in the diel studies should be recorded. The three sampling depths will be 25 cm below the water surface, mid-depth, and 25 cm above the pond bottom. The parameters to be measured during the diel studies are:

- Dissolved Oxygen
- Temperature
- pH
- Wind (cumulative between sampling times)
- Solar Radiation (cumulative between sampling times)

Information about the fish and shrimp used in the experiments should be recorded as follows:

- Stocking
    - Total Number
    - Total Biomass
    - Individual Weights (of 10% sample)
    - Individual Lengths (of 10% sample)

- Monthly Sampling
    - Total Number in Sample
    - Total Biomass of Sample
    - Individual Weights
    - Individual Lengths
    - Reproduction Weight

- Harvest
    - Total Number of Stocked Fish Remaining
    - Total Biomass of Stocked Fish
    - Individual Weights (10% sample of stocked fish)
    - Individual Lengths (10% sample of stocked fish)
    - Total Number of Recruits
    - Total Biomass of Recruits

The following pond soil characteristics are to be determined at the beginning and end of each experiment:

- pH
- Phosphorus
- Organic Matter
- Total Nitrogen
- Cation Exchange Capacity
- Metals - Aluminum, Iron, Zinc (only when the pond is first used)
- Lime Requirement
- Exchangeable Hydrogen
- Base Saturation

Pond morphology is to be measured when the ponds are first constructed and whenever pond morphology is altered significantly. Measurements to be taken are:

- Surface Area (at 10 cm depth contours)
- Volume (at 10 cm depth contours)
- Drawing, top view, with scale

The composition of lime, inorganic, and organic fertilizers is to be determined when supplies are delivered and, for organic materials, just before they are totally used up, but not less frequently than once a month. Characteristics to be determined are:

- Percent Dry Matter
- Nitrogen
- Phosphorus
- Chemical Oxygen Demand
- Lime Neutralization Value (for lime only)

The quantities of lime and other amendments must be carefully recorded whenever they are added to the ponds.

Reference ponds are to be established and operated at each station starting the second year of this work plan.

OPTIONAL MEASUREMENTS

CRSP projects may collect any data, in addition to those data specified under Required Measurements, which they deem appropriate for a particular study. The methods specified in the Summary of Accepted Analytical Methods (Section 3, page 44) or in the appendices (Section 4, page 53) should be used. If a method for a particular parameter is not specified in Section 3, a method from *Standard Methods* (APHA et al., 1985) should be used whenever possible and the Materials and Methods Subcommittee of the CRSP Technical Committee should be informed. If problems are encountered while using the accepted method for a particular application, the Materials and Methods Subcommittee should be contacted. If optional measurements are made and researchers wish to have the data included in the data templates, the Data Base Manager (at the Program Management Office, Oregon State University) should be contacted.

DATA SUBMISSION

All data should be submitted to the CRSP Database Manager on either Lotus 1-2-3® or Microsoft Excel® worksheets, following the formats and procedures in the most recent CRSP *Instructions for Data Entry*. Data and accompanying text for the CRSP *Data Reports* series should be submitted to the CRSP Program Management Office within six months of harvest of each study. Please contact the Data Base Manager with questions regarding verification of data. The Data Base Manager will print the verified data for publication in *Data Reports* unless other arrangements are made in advance.

Appendix D. Calculation of Primary Productivity from the CRSP Central Data Base

Primary productivity and production efficiency are calculated from the data available in the CRSP database by using an oxygen balance based on the DO and temperature measurements taken at three depths during the 24-hour sampling cycles. The mass balance for dissolved oxygen in a pond can be written as:

DO RATE OF CHANGE = DO GROSS PRODUCTION - DO RESPIRATION+ DO DIFFUSION

The hourly rate of change of dissolved oxygen (DO) is estimated from the "depth-averaged" measurements and is then adjusted for diffusion to yield hourly net productivity. Hourly net productivity is adjusted for estimated pond respiration to yield hourly gross primary productivity. The hourly productivity is then summed to yield total daily primary productivity. The detailed calculations are described below, and have been integrated into an Excel spreadsheet which is available from the Davis DAST.

Data needed:

Wind Speed (m/s)	Template A
Temperature (°C)	Template D
Pond Depth (m)	Template B
O_2 Concentration (mg O_2/L)	Template D

Description of Calculations:

1) Dissolved oxygen (DO) and temperature data are depth averaged to yield single pond temperature and DO values for each of the sampling periods:

DO_I = Average ($DO_{I,surface}$, $DO_{I,mid}$, $DO_{I,bottom}$)

$TEMP_I$ = Average ($TEMP_{I,surface}$, $TEMP_{I,mid}$, $TEMP_{I,bottom}$)

where:

DO_I = Depth-averaged dissolved oxygen concentration at time T_I (mg/L)

$TEMP_I$ = Depth averaged temperature at time T_I (°C)

I = Number of the six sampling intervals (0 - 5)

2) The hourly rate of change of average pond temperature and DO are calculated for each sampling interval.

TRC_I = $TEMP_{I+1}$ - $TEMP_I$ / T_{I+1} - T_I

$DORC_I$ = DO_{I+1} - DO_I / T_{I+1} - T_I

where:

TRC_I = Temperature rate of change in interval T_I (°C/h)

$DORC_I$ = Dissolved oxygen rate of change in interval T_I (mg/L/h)

3) The duration of each sampling interval according to CRSP sampling procedures is approximately 4 hours; however, variations in the times of the recorded data caused the sampling interval to vary. To interpolate the data over 24 daily sub-intervals, the duration of each sampling interval is determined and is divided into 4 approximately hourly sub-intervals.

$$\Delta T_I = (T_{I+1} - T_I)$$
$$\Delta T_i = \Delta T_I / 4$$

where:

ΔT_I = Duration of time interval between samplings (h)
ΔT_i = Duration of time sub-interval (h)
i = Number of time sub-interval (0-23)

This process is repeated for each time interval T_I

4) The average pond DO concentration and temperature are interpolated for each sub-interval to complete the 24 hour cycle.

$TEMP_i$ = $TEMP_{I+j} \bullet (TRC_I \bullet \Delta T_i)$, for j between 0 and 3.
DO_i = $DO_{I+j} \bullet (DORC_I \bullet \Delta T_i)$, for j between 0 and 3.
j = Number of time sub-interval within each interval (0-3)

This process is repeated for each time interval, T_I obtaining values for i between 0 and 23.

5) The upper layer DO concentration and temperature are interpolated for each sub-interval for use in determining the rate of diffusion across the boundary layer.

$TEMPS_i$ = $TEMPS_I + i \bullet (TEMPS_{I+1} - TEMPS_I) / 4$, for i between 0 and 3
DOS_i = $DOS_I + i \bullet (DOS_{I+1} - DOS_I) / 4$, for i between 0 and 3

where:

TEMPS = Temperature in the top or surface layer (°C)
DOS = Dissolved oxygen concentration in the top or surface layer (mg/L)

6) The O_2 saturation concentration is determined for each sub-interval in the upper layer from the empirical equation by Elmore and Hayes (1966).

$$SDO_i = 14.652 - 0.41022 \bullet T3 \bullet TS_i + 0.007991 \bullet TS_i \wedge 2 - 0.000077774 \bullet TS_i \wedge 3$$

where:

SDO = O_2 saturation concentration (mg/L)

7) The rate of oxygen diffusion into the upper pond layer is calculated for each sub-interval from the wind speed, and oxygen concentration gradient according to the empirical equation by Banks and Herrera (1977).

$$\text{Diff in}_i = (SDO_i - DOS_i)\,(1/Z\,[\,0.03 \bullet W \wedge 0.5 - 0.0132 \bullet W + 0.00157 \bullet W \wedge 2]\,)$$

where:

Z = depth (m)
W = Wind speed (m/s)

8) The nighttime pond respiration for each sub-interval is calculated as the nighttime rate of change of average pond DO less diffusion in. This value is then averaged and used as a rough estimate of daytime pond respiration, in accordance with the procedures suggested by Hall and Moll (1975) and others. This pond respiration rate is not adjusted for temperature effects because of lack of data for this calculation in the CRSP database, and is therefore likely to be an underestimation of actual daytime pond respiration.

$NTPR_i$ = $DORC_i$ - Diff in_i, for all night time i's.
PR = Average ($NTPR_i$)

where:

$NTPR_i$ = Night time pond respiration rate (mg O_2/L/h)
PR = Average pond respiration rate (mg O_2/L/h)

9) The phytoplankton production rate per hour is calculated for each sub-interval as the DO rate plus pond respiration less diffusion in. The daylight production rates (< 0) are then summed to yield daily primary productivity.

GPP_i = $DORC_i$ + PR - Diff in_i
GPP_{tot} = Σ GPP_i

where:

GPP_i = Gross primary productivity (mg O_2/L/h)
GPP_{tot} = Gross primary productivity (mg O_2/L/day)

When using these calculations, it should be kept in mind that because nighttime pond respiration is used as an estimate of daytime respiration, this term is likely to be underestimated when there is a significant temperature differential between day and night. This means that the daily primary productivity also is likely to be underestimated in this case.

References

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1985. Standard methods for the examination of water and wastewater. 16th edition. APHA, Washington D.C. 1268 pp.

Banks, R. B., and F. F. Herrera. 1977. Effects of wind and rain on surface reaeration. J. of Env. Eng. Div., ASCE 103 (EE3):489-504.

Elmore, H. L., and T. W. Hayes. 1960. Solubility of atmospheric oxygen in water. Jour. Sanit. Eng. Div., ASCE 86(SA4):41.

Hall, C. A. S., and R. Moll. 1975. Methods of assessing aquatic primary production. pp 19-53 *in* H. Leith and R. H. Whittaker (eds) Primary productivity of the biosphere. Springer-Verlang, New York.